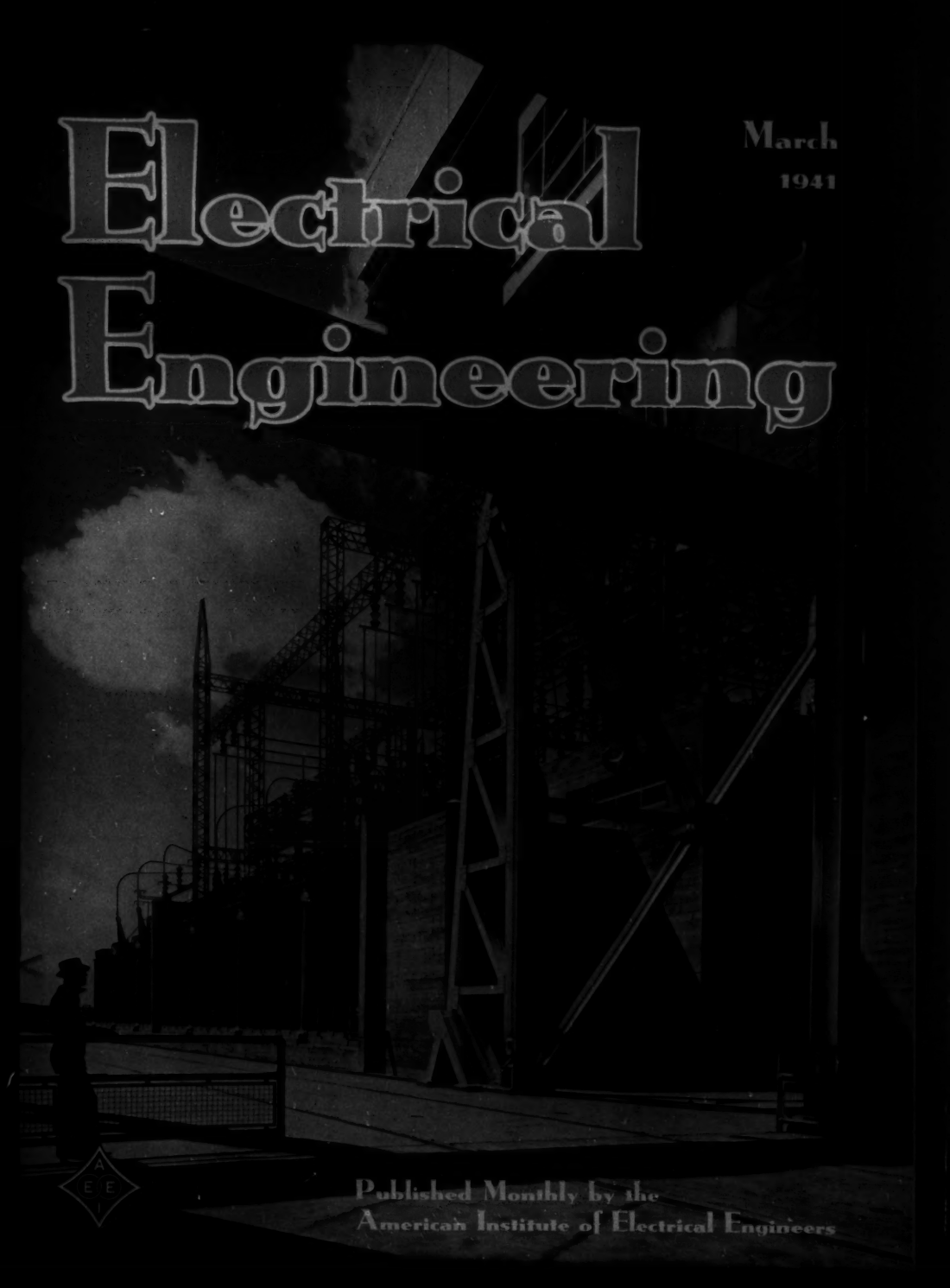
Electrical Engineering

March
1941



Published Monthly by the
American Institute of Electrical Engineers

To Measure LIGHT
ELECTRICALLY

Testing a 60-inch searchlight

MEASURING the 800,000,000 beam candlepower of a searchlight would certainly have been a headache in the days when light intensities were measured by means of a standard measuring candle and a grease spot on a piece of paper. Today this task, which requires a minimum of 100 separate measurements to explore the light intensity throughout the beam, is comparatively simple—thanks to the development of special electric measuring equipment.

In our Illuminating Laboratory, where the candlepower of searchlights, floodlights, and streetlights is measured, the photometric measuring device consists of a combination of light cells and a galvanometer.

When measuring beam candlepower, the light beam is directed upon a collecting device composed of light cells which convert light energy into an electric current. This current, which is directly proportional to the light intensity, is transmitted to a sensitive galvanometer, the scale of which is calibrated in foot-candles. Thus, it is possible to obtain quickly and accurately the many readings needed to determine the light-distribution pattern and the beam candlepower.

The light cell is also the basic element in several other G-E light-measuring instruments: the light meter, used to measure light intensities in homes, offices, and factories; the exposure meter, used in photography; and the luximeter, used primarily to determine the degree of pasteurization of milk.

These accurate, dependable instruments are typical of our complete line of equipment available for the measurement of all electrical quantities—available in dozens of styles, indicating and recording, and in ratings to fill every need. If you have a problem that involves measurement, let us help you solve it. General Electric, Schenectady, N. Y.

HEADQUARTERS FOR ELECTRICAL MEASUREMENT

GENERAL ELECTRIC

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AN OPEN LETTER TO ELECTRICAL MANUFACTURERS

CAREFUL INVENTORY PLANNING

An Important Aid to Our National Defense Program

THE DEFENSE PROGRAM is imposing an expanding demand upon our domestic economy for every type of material.

Real shortages have developed in some markets, but many current "bottlenecks" in supply are more apparent than real. It is important that we distinguish between true shortage and the kind of shortage that results from frenzied buying or improper planning. If we fail to do this, the apparent bottlenecks will be as conducive of starting the vicious cycle of advancing prices as any real scarcity. A serious price inflation is our most dangerous internal enemy. Only war would be a greater catastrophe.

The recent shift from normal plant operation, with little or no back-log of orders, to the current situation of operating with large back-logs, seriously affects the problem of production planning. We must modify our inventory methods to suit the new conditions, or we may unwittingly create a situation of hoarding and bring with it the usual consequences of that harmful practice.

To illustrate: Let us take the case of magnet wire that is supplied on returnable reels and spools. In ordinary times, magnet wire users often find it expedient to carry an assortment of wire sizes and insulations to meet the varying and unpredictable demands of their customers. Under hand-to-mouth operating conditions, long range planning for production is impossible.

With a large back-log of unfilled orders, scheduling for specific production for a long period becomes a necessity. The uncertainty of demand for special models is reduced or eliminated, and the need for a mixed inventory of wire sizes and insulations no longer exists. With a known demand for daily or weekly amounts, inventories of slow-moving supplies can be safely minimized. By thus scheduling incoming supplies to closely meet current needs, a vast supply of idle spools and reels can be released for repeated use.

A shortage of reels and spools is not easily corrected. Not only is time required to produce the added spools and reels, but the additional investment is a matter of serious import. The failure of wire users to speed up the return of reels and spools may shut down insulating machines and curtail essential production of insulated wire.

Sales departments of electrical manufacturers should recognize the necessity of close planning between their own plants and those of their customers. Every salesman should be a production liaison officer during this critical period. The responsibility for correcting these apparent bottlenecks of supply rests squarely upon customers and vendors alike.

It is the duty of industrial managements, for patriotic reasons as well as for their own self preservation, to coordinate their production planning with that of their suppliers and customers. If this is done . . . if we can eliminate the apparent bottlenecks of supply . . . the danger of inflation will be minimized, and the cause of national defense greatly accelerated.

W. Phipps Jacobs
President

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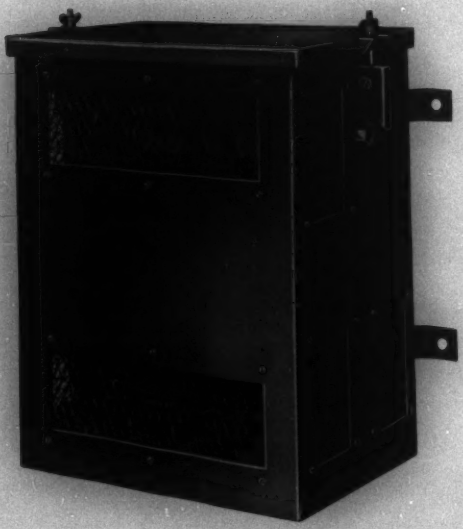

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of OKOLITE SUBMARINE POWER CABLE

Puget Sound Light and Power Co. Installation Increases Bremerton District Power Supply

Installed to supplement two Okonite submarine cables laid in 1926 and still operating perfectly, this new 23000 V. Okolite insulated non-leaded Submarine Power Cable was made, shipped and installed in a single length.

Materials and specifications for construction were as follows:

DESIGN:	3 conductors, 250,000 C. M. 61 strands .0640 Okoloy-coated copper wire, 29/64" Okolite insulation, each conductor taped, cabled together with double wrapped tape binder, 2 layers saturated jute, #4 B.W.G. galvanized steel tape, 5/64" saturated jute.
OVERALL DIAMETER:	4.38 inches.
WEIGHT:	Over 15 lbs. per foot.
TOTAL WT. OF CABLE:	354,000 lbs.

Total capacity provided by these cables will be ample to take care of immediate needs and allow for added loads in the future.

THE OKONITE CO., PASSAIC, N. J.
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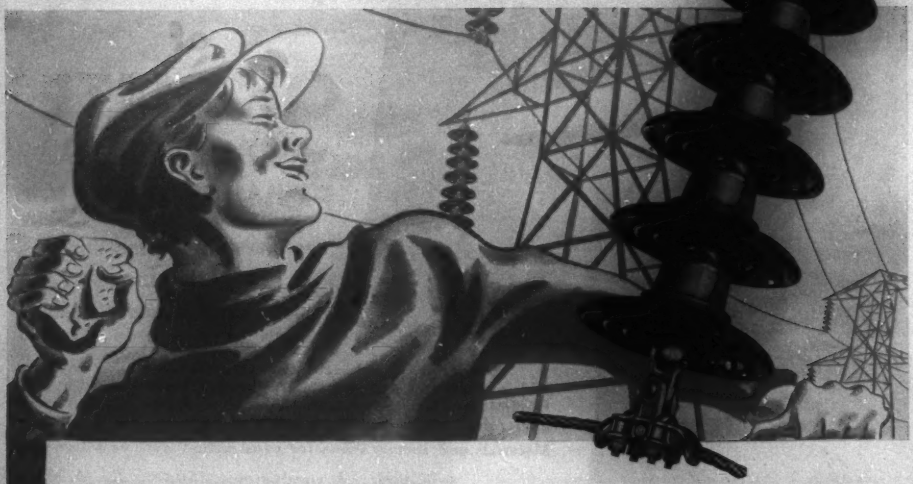

● Greater resistance to breakage—actually 300 per cent of former values! That's the extra value offered in O-B's No. 25620 and 25622 suspension insulators—and at no premium in price. Measurements by the proposed A.I.E.E. standard method show that *all* of O-B's suspensions have much higher impact strengths, but the 25620 and 25622 were singled out because they're the most widely used and best known suspensions in the industry and have by far the longest service records. Check your own experience with these insulators, and then consider what the greater impact strength will do in reducing breakage from handling, falling objects, rock throwing and gun fire. You're certain to obtain longer service from these units—already noted for their long life—which means even greater value for your insulator dollar!

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Electrical Engineering

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for March 1941—

The Cover: Part of the powerhouse area at the Pickwick Landing Dam of the Tennessee Valley Authority on the Tennessee River

Photo courtesy TVA

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VOLUME 60 NUMBER 3

Published Monthly by the

American Institute of Electrical Engineers

(Founded 1884)

ROYAL W. SORENSEN, President H. H. HENLINE, National Secretary

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Entered as second class matter at the Post Office, Easton, Pa., April 20, 1932, under the Act of Congress March 3, 1879. Accepted for mailing at special postage rates provided for in Section 538, P. L. & R. Act of February 28, 1925. ¶ Publication Office: 20th & Northampton Streets, Easton, Pa. Editorial and Advertising Offices at the headquarters of the Institute, 33 West 39th Street, New York

¶ Statements and opinions given in articles and papers appearing in "Electrical Engineering" are the expressions of contributors, for which the Institute assumes no responsibility.

¶ Correspondence is invited on all controversial matters.

High Lights • •

Total Defense. Characterizing the current world upheaval as but part of a long-term cycle of social revolution which is manifesting itself in one way in Europe and in other ways in America, President Charles E. Wilson of the General Electric Company told AIEE winter conventioners that prompt and definite action is required to preserve the American free-enterprise System—in fact the democratic way of life itself. On the basis of a realistic analysis, he submitted a step-by-step plan of possible action and challenged industrial leaders and thoughtful private citizens to take the initiative without delay—to "arise or be forever fallen" (*pages 99–105*).

New Subway. If all subway and elevated railroad trackage in New York City were laid as single-track line, it would extend almost from New York to Chicago. Although the Sixth Avenue line which was completed in December 1940 comprises only 7⅓ miles of track, a very small proportion of the total, its total cost was about $60,000,000. It is regarded as the most difficult piece of subway construction ever undertaken, and involved almost every type of construction method (*pages 110–20*).

Transformer Noise. The audio noise of transformers, which must be limited near inhabited districts, has been determined to arise from the change in dimensions produced in the core steel by the alternating magnetic flux. The basic noise may be increased by resonant vibration of mechanical parts. Theoretical relations for the sound produced have been derived and tested on commercial transformers (*Transactions pages 109–12*).

Driven-Ground Characteristics. Test data have been obtained on the impulse and 60-cycle characteristics of common rods driven in natural soil largely of clay composition; results have been analyzed in the characteristic curve of the ratio of impulse to 60-cycle resistance, for impulse currents representing conditions ranging from a traveling surge to direct strokes of lightning (*Transactions pages 123–8*).

Smaller Hollow-Pipe Lines. Relatively large transverse dimensions, comparable in magnitude to the wave length, are the chief disadvantage of the hollow-pipe type of conductor for ultrahigh-frequency electromagnetic energy; several cross-sectional shapes of smaller dimensions have been described, and the theory of one, the "septate coaxial cable" derived (*Transactions pages 119–22*).

Edison Medalist. A "pioneer among pioneers" is how George Ashley Campbell, 1940 Edison Medalist, is characterized by AIEE Past President Frank B. Jewett, his "associate and friend for more than 35 years" (*pages 106–09*).

Cable Transmission of Pictures. A new system of transmitting facsimile matter from London to New York by submarine cable was made available to the public in April 1939. Unique measures have been used to insure undistorted images and maximum speed within the limited frequency system available through the cable, and special networks and amplifiers have been developed (*Transactions pages 105–08*).

Automatic Aircraft Control. Developments have proceeded to the point where "with nominal additional development it will be possible, in the near future, to cause an airplane to take off, to continue in automatic flight on a predetermined course, and then to land automatically at a predetermined place, entirely without human control" (*pages 122–6*).

Initial Breakdown Voltage. An approach toward a more generally applicable theory for predetermining spark-over and corona starting voltages has been made by calculating initial breakdown voltage by means of formulas developed for two quantities characteristic of the gas in cases where the field, if nonuniform, verges toward the cathode (*Transactions pages 99–104*).

Lightning Protection. An analysis of trouble data showing the degree of protection afforded to medium-voltage lines by various values of insulation strength has been made by one company and the data used in selecting minimum insulation values on which to base improvement of its lines to reduce lightning trouble (*Transactions pages 128–32*).

Instability of Synchronous Machines. A general stability criterion has been developed, which considers the mutual interactions of hunting, self-excitation, and loss of synchronism, hitherto treated only as separate phenomena, and thus provides an analysis that indicates the limitations and proper fields of reference of the approximate formulas (*Transactions pages 116–19*).

Electric Strength of Air. An investigation has been made of the electric strength of air at pressures up to 21 atmospheres. Sparking voltages have been determined for air under pressure as measured with 60 cycle alternating voltage applied to sphere gaps, and deviations from the linear pressure-voltage relation that exists at low pressures noted (*Transactions pages 112–15*).

Automatic Printing Ammeter. A new instrument has been developed which will automatically read and record in numerals, at predetermined time intervals, the ampere loading on 50 different electric circuits (*Transactions pages 93–9*).

Standard Impulse Voltages. Culminating more than ten years' work by a joint committee composed partly of AIEE representatives, a standard series of basic impulse insulation levels has been adopted (*page 121*).

Television Standards. The 22 standards for commercial television proposed to the Federal Communications Commission by the National Television Systems Committee and scheduled for public hearing March 20 are presented in full in the "Current Interest" section of this issue (*pages 145–7*).

Power-System Governor. A new type of electrical control has been developed by which a standard power-system governor may be made sensitive to system load as well as to frequency, and which may be used without sacrifice of reliability (*Transactions pages 89–92*).

Breakdown Strength of Air and Freon. D-c breakdown studies in air and in Freon 12 at high pressures and in a uniform field have been extended to higher voltages; for air, to 1,000 kv, and for Freon to over 350 kv and to 135 pounds per square inch absolute (*Transactions pages 132–5*).

Bessel Function $I_n(x)$. Additional values for the modified Bessel function $I_n(x)$ have been computed, using the arguments 0.1, 0.2, 0.3, etc., and the enlarged five-figure table is presented (*Transactions pages 135–6*).

Coming Soon. Among special articles and technical papers currently in preparation for early publication are: an article describing recent applications of radio to the remote indication of meteorological elements by Harry Diamond; a paper on a new air circuit breaker with 250,000-kva interrupting capacity by R. C. Dickinson (A'37) and R. H. Nau (A'40); a paper on prime mover speed governors for interconnected systems by R. J. Caughey and J. B. McClure (A'29); a paper on engineering requirements for program transmission circuits by F. A. Cowan (M'29), R. G. McCurdy (F'34), and I. E. Lattimer (M'35); a paper on the service-factor rating of arc-welding generators and transformers by R. C. Freeman and A. U. Welch (A'36); a paper on system stability by F. W. Gay (F'32); a paper on a new method for introducing relaxed initial conditions to transient problems by W. C. Johnson (A'35); a paper on magnetic fields in watt-hour meters, dealing with the effects of wave form on the registration of single-phase watt-hour meters, by C. A. Keener (M'28), M. A. Faucett (M'35), and N. S. Helm; a paper on atmospheric variations and apparatus flashover by P. H. McAuley (A'36); a paper on secondary networks to serve industrial plants by C. A. Powel (M'20) and H. G. Barnett (A'33); a paper on corrosion problems relating to the water-cooled steel-tank power rectifier by A. J. Renscheid; a paper describing the Varioplex, a new development in telegraphy, by E. R. Shute (M'17); a paper on arc-backs in ignitrons in series by J. Slepian (F'27) and W. E. Pakala (A'38); and a paper describing an electron microscope for practical laboratory service by V. K. Zworykin (M'22), J. Hillier, and A. W. Vance.

Subscriptions—$12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, Philippine Islands, Central and South America, Haiti, Spain, Spanish Colonies; $13 to Canada; $14 elsewhere. Single copy $1.50. ¶Address changes must be received by the 15th of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge. ¶ELECTRICAL ENGINEERING is indexed annually by the Institute, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London). Copyright 1941 by the American Institute of Electrical Engineers. Printed in the United States of America.
Number of copies this issue 24,100

Total Security—A Challenge

By Charles E. Wilson

President, General Electric Company

◆ ◆ ◆ With the foresight that comes of a career closely packed with varied experience, with the courage that comes of purposeful study and relative youth, and with the forcefulness that comes of conviction and determination, Mr. Wilson presents here his realistic survey of a situation that is of vital significance to every American—in fact, to all democracy.

◆ ◆ ◆ This thought-provoking challenge, presented as a basis for discussion and action, comes from one of America's youngest and foremost industrial leaders—a man who came to the top "the hard way" in the highly competitive American free-enterprise system for which he here seeks a means of preservation. The "Letters to the Editor" columns are open for discussion of this timely topic.

I SHOULD LIKE TO SUBMIT what I believe to be a realistic view of both the world conflict and its impact upon our way of life. Then, against that background, should like to invite constructive consideration of a ogram—a constitution for the American free-enterprise stem, if you will—which, with the support of serious-inded citizens, could be—and, I would earnestly hope, ould be—a worthy contribution to the solution of the ceedingly complicated problem of preserving our demo-atic way of life and our free-enterprise system in the rk decades ahead. In this statement I am anxious to ve you see evidence of an ambition to serve you, and merica, rather than to seek support of a particular plan. fact, it is my hope that all of this presentation will be received as an effort to serve the land and the institutions we all love so much.

Now, certainly in these critical and confusing times, a clear conception of the character and significance of the world conflict is essential, for, obviously, if we are to proceed to the development of a program which will contribute to our "total security"—total security on our moral, physical, and economic sectors—we must start from a realistic premise. And proceed we must, promptly, in the development of such a program.

In truth, "it is later than we think"; and chaos can be the consequence of confusion and procrastination.

In the course of this presentation I may seem, at times, to express some thoughts which might be interpreted as a criticism of industry. Therefore, at the outset, I should like to establish understanding on that point. My whole career has been in industry, and, fortunately, the character of that career has been such that I have been brought into intimate association with almost every form of industrial and commercial enterprise. Out of these associations there has grown a tremendous pride in the accomplishments of industry, as well as an intense admiration and respect for the progressive citizens who, in the preponderant majority, compose it—the conscientious citizens in the shops and offices, in the drafting rooms, and in positions of management of every degree and kind, who, operating as organizations in enlightened enterprises, have given employment and enjoyment to millions of people while providing America with the highest degree of economic security and the highest standard of living in the world. Therefore, in anything which I may later say which seems to suggest shortcomings, I hope you will see in my comments not a presumptuous inclination to criticize, but, instead, a positive indication of my infinite confidence in the ability of industry to do an even better job in the building of an ever-better America; a confidence which is coupled with a driving desire to have industry, as an integrated entity, go forward faster and more fruitfully than it ever has before.

An address delivered January 29, at the 1941 AIEE winter convention. Philadelphia, Pa.

WILL BE NO "RETURN TO NORMAL"

Having given you that assurance, I shall now proceed to outline my conception of the true character of the world conflict—with one intervening assertion. This is that, in order to save you time, I shall speak rather emphatically, assured that you will accept my words for what they really are: Words which are merely the earnest expression of the convictions of some of your fellow-citizens who are concerned, above all else, with their country's welfare; the carefully considered words of fellow-countrymen of yours who seek the collaboration of the splendid minds

which comprise this body in finding the most effective means of preserving individual initiative and private enterprise as the mainstays of our economic life.

What, then, is the true state of the world as I see it? It is this:

The world is immersed in more than a war of historically conventional character. Our own beloved nation is involved in more than a "temporary emergency" from which, after a few years, it will emerge and return to "normal" living in a "peaceful" world; a world made "peaceful" by the fact that some "national leaders" had gained military ascendancy over others and had thus forced the signing of some papers. In the critical circumstances confronting the world in general, and our country in particular, failure to recognize these facts is not only unrealistic but dangerous.

Instead, there must be a complete, realistic comprehension of the fact that the world—our nation included—is passing through what history may later record as the second stage of a revolutionary movement of the masses; a movement born during World War I and likely to last, with intermittent armistices of one kind or another, for two or three decades more. We must fully realize that this is a movement based upon a sense of frustration—an emotional manifestation frequently approaching unreasoning, sacrificial hysteria—and we must see that, as such, it can be turned to a course of reason only by reasonable and sacrificial actions of a character which appeal to the emotions and the aspirations of the masses more than do the actions and the appeals to which they are now responding.

Today the practical controlling fact is that hundreds of millions of people throughout the world have been persuaded, to the point of evangelistic conviction, that the capitalistic system is the cause of the economic insecurity of the common man and that, as the root of his economic ills, this system must be drastically modified, or failing that, destroyed.

TOTALITARIAN LEADERS ARE BUT SYMBOLS

Recognition of the revolutionary character of this world-conflict will lead also to a fuller realization of the fact that current "totalitarian" leaders are but symbols of this movement. Further, from this realistic point of view, it will be seen that, notwithstanding the ruthless force exercised by these leaders in beating the more mature segments of their peoples into a state of resentful spiritual resistance, there is abundant evidence that they are strongly sustained as symbols by a preponderant majority of the people under 40 years of age. These are the newer generations, born and bred and ideologically conditioned under the almost exclusive influence of the "new" leaders. They are the generations which, after willingly sacrificing their political freedom, are now sacrificing their lives; and they make these sacrifices willingly because they sincerely believe that, through these leaders, a better and broader form of economic freedom will be gained, either for themselves if they survive, or for succeeding generations if they pay the supreme sacrifice.

This realistic point of view also leads to the sad conclusion that should these symbols meet the disaster or the death so widely and so earnestly wished upon them, this revolutionary movement most probably would suffer no more than temporary confusion while substitute symbols were being elevated to leadership. Further, it suggests that such an eventuality might lead more easily to chaos than to a return to conventionality.

PEOPLES SEEK ECONOMIC FREEDOM AND SECURITY

But as a world movement, the scope of this conflict extends beyond the sphere of these symbols. In the Central and South American countries, manifestations of it have been and continue to be common; and this is equally true of many parts of the British Empire. Although the war aims of England have not been officially expressed, public speeches, parliamentary debates, the prominence given labor leaders, and many other indications of public sentiment supply ample evidence of the ambition of the British people. From this evidence, it may clearly be seen that the ardent aim of the millions of heroic common people in Britain—first to defend themselves against the dictators, and finally to destroy them—arises basically from the deep-held desire to insure for their masses and for their fellowmen in other lands a much larger measure of economic freedom and security than the conventional capitalistic and imperialistic system has previously provided. True it is, of course, that they treasure the democratic tradition, but let us be sure to see that they insist upon its preservation in an atmosphere of economic freedom for all.

Therefore, while political freedom happily has been preserved in the British Isles, in its associates in the Commonwealth, and in the United States, it is important to remember that in these countries many economic controls willingly have been granted to government by the masses of the people in exchange for promises and for performances serving the mass revolutionary aim: More economic freedom and security. Hence, although in the United States, so far, we have had no more than an acceleration of the *evolutionary* process—rather than the *revolutionary* process—it should be borne in mind that the aim of the majority of the American people, as evidenced by their insistence that this acceleration continue, has been substantially that of the revolutionaries. Further, it should be remembered that in the last national election both presidential candidates, recognizing the aspirations of this majority and realizing that this was a mass movement overshadowing all partisan considerations, pledged their efforts to an enlargement of economic security for ever larger stratas of society; and that these candidates differed only regarding the manner in which this aim might best be attained.

CHALLENGE TO FREE-ENTERPRISE SYSTEM

Now, if you believe as strongly as I do that this is a realistic appraisal of the aspirations and the forces underlying the conflicts and confusions abroad in the world today—the conflicts and confusions which have brought civilization almost to the brink of chaos—your natural

questions will be those with which I struggled; such questions as:

——What more can the free-enterprise system do, in the face of this world revolutionary movement; a movement heretofore unmatched, either in extent, or in emotional intensity, or in destructive potentialities?

——How, in the midst of this dynamic world disorder, shall the capitalistic system—or what we in the United States call the American free-enterprise system (which, parenthetically, I should like to call the capitalistic system in its most constructive form)—be sustained in its most useful form; the form in which it can be the primary provider of economic security for all of the people at all times—in times of peace and plenty, in times of depression, in times of national emergency, and in times of war?

——How may an ever broadening bulwark of public faith be built to protect this free-enterprise system, seeking to serve this purpose, against its communistic and totalitarian enemies?

——How may we control and conquer the causes of suspicion and condemnation which too often create breaches in this bulwark of public faith upon which the protection of the system depends?

Basically, the answers to these questions seem simple; practically, the solution of the problems they present is most difficult.

The simple answer seems to be that again, and again, and again the financial and managerial components of our free-enterprise system must prove by deeds as well as by words their full comprehension of their social responsibilities (their deep sense of public service) and their unmatched capacity to positively plan, to put into effect, and to police a program of industrial and commercial progress acceptable to the majority of our people; people whose economic security and destiny are vitally affected by the decisions of these controlling components of the system. In the circumstances surrounding us today, who will doubt that this action must be prompt and positive, and of a character which will demonstrate beyond the chance of successful challenge that the public-spirited people administering private enterprise inherently and actually excel the people comprising political organizations (no matter how sincere the intentions of the latter may be) as instrumentalities for insuring an ever-increasing measure of economic freedom and security for all of the people (save the indolent) all of the time?

MORAL SECURITY IS FIRST DEFENSE

Never before has the American free-enterprise system been confronted by such a serious challenge. And never before has there been—and perhaps never again will there be—such an opportunity, or such an obligation, to prove the full worth of this system as an efficient, economical, and trustworthy servant of society. Moreover, in these dark days we may be sure that as the American free-enterprise system sees this enlarged opportunity, as it assumes this greater obligation, and as it proves still more fully its worthiness, it will re-establish emotional bonds of mutual regard and respect between all elements of our economy; the bonds of national unity which will serve as a firm foundation for our *moral* security, the first fortification of our political and economic freedom.

Happily, it may be stated as a fact that this first fortification is rapidly rising; and, that being true, the comforting consequence is that behind it there is rising with equal rapidity the vast and varied reservoir of materials required for our *physical* security. For that physical security, our immediate necessities have been stated repeatedly and comprehensively by our Commander-in-Chief, and by those drawn from management, labor, and government upon whom he has placed the responsibility of organizing, co-ordinating, and leading our immense industrial resources to the end that our nation may be in fact—and on time—the "arsenal of democracy." Therefore, on the subject of our necessities for physical security, let it be enough for me to say here that everything I have said hereinbefore has had as one of its most important aims the lending of emphasis to the urgency of meeting our *physical* needs, as well as our *moral* needs, for national security. Further, I hope that I have helped to make clearer the fact that these physical needs are so frightfully pressing that absolutely nothing else—no other conceivable consideration—can possibly be important enough to justify the slightest interference with maximum progress in the provision of these materials to the full extent of industry's total capacity.

DEMOCRACY'S DELIBERATIVE PROCESSES

For my part, I am sure that enlightened industry in every part of our land is fully conscious of that fact; and I am equally certain that it is proud of the additional fact that its experience, its skills, and its forms of organization place it in a front-line position to provide most of the materials needed in this great emergency. That being true, no one need doubt that industry will do its full patriotic duty; and no one need fear that, in the performance of this duty, it will fail to employ every resource required for the provision of the materials needed for our nation's physical security just as fast as human ingenuity and an intense desire to serve makes possible—and that I'm sure will be awfully fast for, after all, we are Americans.

However, as we proudly remember that we are Americans "capable of performing production miracles," let us not forget that the deliberative processes of democracy are inherently slow in arriving at decisions, particularly in times of crisis; and that much of the defense delay which distresses our nation today is caused by the very processes which we are preparing to defend. This is said not to criticize the democratic process—for that I hold to be the greatest form of free government that man ever devised; but I do say that, as a nation, we must place the principal responsibility for deferred and indecisive action where it belongs: upon the whole people, whose reactions and aims are so very slowly reflected through the democratic deliberations of their chosen representatives.

To this I also may add that many of the delays within industry itself probably may be traced to the fact that the democratic deliberative process is a practice common also in the determination of decisions within the institutions of enlightened enterprise.

PHYSICAL SECURITY IS PARAMOUNT

Now, for continental physical security, the relative order of urgency seems to be first the provision of materials

and the training of men for the Navy, for the Air Corps, and for the Army, closely followed by the need for enlarged reserves in our power and transportation facilities. In the broader and more realistic sense, we may see that defense materials for Britain, or for any other nation combating the supporters of the philosophy of force, are in fact an integral part of our own national defense. Here again the realistic view will clearly reveal that, as a nation, we now must be prepared to pay *any price* for the time that we have lost and for the time that we require actually to provide our own national and hemispheric defense. Taking that view, we shall see that so long as any aid we give Britain or any other nation gives us this precious time, we serve ourselves best—even selfishly, if you will—by submerging all other conflicting and confusing considerations until after this elemental purpose of our aid has been served.

Therefore, as we now come to a consideration of our economic security, I wish to re-emphasize with all the force at my command the fact that the requirements for our *physical* security come *first*, without quibble or question; and that any economic consideration must immediately be subordinated the moment it comes into conflict with our primal concern for the protection of our lives and liberties.

Now, against this background, I should like to present the program I mentioned at the outset; a program which attempts to establish a general pattern of the stages and steps I consider essential to the further fortification of our political freedom and the extension of economic freedom to our whole society through the instrumentality of the people who comprise the American free-enterprise system acting in close, cordial, and constructive co-operation with the people who comprise the Government of the United States.

While the steps under the various stages will be set before you in what appears to be the approximate order of their importance, I am sure that it will be apparent to you that each is not a distinct, successive step. Obviously, some require continuity from the time of their initiation; and these I shall try to identify as I go along. Others are overlapping in various degrees. Still others are temporary. Nevertheless, their interrelation will be clearer, I think, if you have the relativity of their importance in mind.

PRIVATE ENTERPRISE MUST TAKE THE INITIATIVE

Connected with the relativity of these stages and steps, in terms of importance, I should like also to emphasize the importance of timing the actions I shall propose by stages. This I consider to be extremely important, because some of these steps, taken too soon or too late, could very easily have an effect contrary to that sought.

Also, it will be evident that some of the elements of this pattern are logically within the province of government; that others are logically within the province of private enterprise; and that still others are of an uncertain category. The point to be re-emphasized in this connection—and it is a point requiring very special emphasis—is that the components of the private-enterprise system should take the initiative in defining the obligations the whole system can and will positively assume, while collaterally and co-ordinately it defines those obligations which it will actively support government in assuming. In this suggestion, I present no thought of arm's-length co-operation, overshadowed by suspicion between government and business. Instead, I seek arm-in-arm concord and co-ordinated effort in the common good; the kind of concord and effort which can, in my judgment, eliminate the causes of conflict, competition, and confusion between government and business.

At this point, also, I should like to recall my remarks made earlier in this discussion suggesting that we might very readily delude ourselves if we fall into the error of laying our plans on the premise that when the next peace papers are signed the national emergency will cease and we shall return to that nebulous state known as "normal living". I recall these remarks in order to make the point here that, in my belief, world conditions in 1943—and 1944—and 1945, coupled with an acceleration in the obsolescence of defense materials, will require this nation to devote much more of its energy and its substance to defense production than is generally believed probable by the majority of people today. Therefore, while I believe that the peak of defense production and employment will be passed during the next two to four years, I also am of the opinion that the prospective reduction in employment, after this point has been passed, may be measured in terms of from three to six million people (rather than ten to twenty million as some quite sincerely believe)—unless the private-enterprise system, in co-operation with government, starts right now to plan the way to keep all employables employed; and in my estimate I include those who may lose their jobs both in direct defense production and in the production of normal needs for which the demand can diminish.

A PROGRAM——RECOVERY STAGE

For our *economic* security, then, upon which our cherished democratic way of life and our dynamic free-enterprise system may depend for survival during the coming dangerous decades, I submit the following program.

The first period in this program I identify as the "recovery stage". This is the stage in which we now are, and in which I believe we shall remain until the Federal Reserve Board's Index of Industrial Production (unadjusted) averages 140 during a two-months period. This figure roughly represents the absorption of 90 per cent of all employables and approximately the same percentage of all effective production capacity now available.

In this recovery stage we need:

1. A sincere, determined, and unswerving devotion to democracy, coupled with a clear understanding of and infinite patience with its deliberative processes; and need I say that this is a primary and everlasting essential?

2. Universal respect for the rules which the people through their freely chosen representatives establish for the protection of their rights; which of course is only another way of saying universal respect for the sanctity and the spirit of the laws of our land; quite obviously an eternal essential.

3. A wholly free and enterprising system of free-enterprise; another continuing necessity.

4. Full-time employment of all employables; this, too, is always essential to total economic security.

5. The free flow of all goods, purchasing power, and enterprise capital for production.

6. The encouragement and development of new inventions, accompanied by aggressive promotion of pioneer products. (Parenthetically, I submit this essential in economic security as a very special responsibility of electrical engineers; and this, too, is a continuing necessity.)

7. Rural electrification and the industrialization of agriculture, to the end that a strong agricultural economy and contented people on our nation's farms may be the constant companions of and constructive contributors to a strong industrial economy comprised of contented people.

8. Development of hemispheric self-sufficiency, through the development of South America as a source of raw materials; a development which should be subsidzied if necessary. Clearly this, too, is a continuing necessity, as I shall later try to emphasize in connection with another reference to our relations with South America.

These, then, are the requirements of the recovery stage.

A PROGRAM——STABILIZATION STAGE

Now we come to what I label the "stabilization stage"; the period immediately after the Federal Reserve Board's Index of Industrial Production (unadjusted) has averaged 140 for two months. The necessities in this stage are as follows:

1. Credit and price control against inflation, against long term commitments on durable consumer-goods purchases, and against nonessential personal loans.

2. Maintenance of a full supply of normal needs of a nondurable character to all stratas of society; still another continuing necessity.

3. An acceleration of the modernization of industry, including within that identity all power, transportation, communication, and other utilities; again a continuing necessity, to the end that we always may be in a position to provide more goods and services for more people at less cost.

4. Gradual reduction in governmental activities, expenditures, and loans connected with all nondefense purposes in the conventional field of private enterprise.

5. Taxation to balance the nondefense budget—a step which, with the one just passed, you will notice I place in the second stage of this program because we want no restraints upon employment and increased purchasing power in the first stage.

6. Industrial development of the temperate zone of South America; another continuing necessity, which should be aided by subsidy in the degree necessary.

HEMISPHERIC SELF-SUFFICIENCY

Here may I interrupt this step-by-step presentation long enough to say that special emphasis is given to the development of hemispheric self-sufficiency and to the industrial development of the temperate zone of South America for these reasons:

It is my belief that, no matter what may be the outcome of the present phase of the foreign revolutionary movement, political and economic slavery—if not actual slavery—will prevail. Fleeing from this slavery—a slavery which will be most intolerable to the best minds in the war-torn countries—the oppressed will find ways, no matter how perilous these ways may be, to migrate to this hemisphere hoping that here in the still new world they will find a haven where a new beginning in an atmosphere of freedom may be made. Similarly situated, our forefathers of every race and creed did this in the seventeenth and eighteenth centuries; and just as, in these centuries, our forebears from across the seas developed our continent, these twentieth century immigrants can develop the South American continent to the advantage of themselves, of the countries of their adoption, and of the whole Western Hemisphere. Therefore, humanitarian considerations connected with these prospective immigrants suggest that we help our South American neighbors to prepare themselves industrially to support these people while the latter in turn are preparing themselves to make their contributions to the industrial growth, to the crafts and culture, and to the security of the continent to the south of us.

In addition to this humanitarian consideration, self-interest suggests this help because a strong, self-sustaining, self-defending South American continent obviously will add immeasurably to hemispheric security and hence to our own security, at less cost to ourselves ultimately.

Further, with their industry growing—and creating, as industry always does, great middle classes which are the mainstays of any nation—our South American neighbors could do much to replace our present and prospective loss of normal trade with the rest of the world; and, again, this would serve the common interests of both continents and strengthen the bonds of mutual understanding and good will.

As I leave this brief consideration of hemispheric collaboration, I should like to make very clear that what I have in mind is, in fact, collaboration with the *interests* of our neighbors in the Americas as the primary concern—not commercial exploitation of the character which, too often, has created hemispheric discord.

A PROGRAM——BACKLOG-BUILDING STAGE

Now, returning to our step-by-step consideration, we come to what may be called the "backlog-building stage"—the stage during which we undertake to dam up a part of the demand for goods in order that we may have a reservoir of nonessential unfilled wants in reserve for the days ahead, when employment connected with defense could diminish in a degree sufficient to be dangerous to our economy and to our way of life. This is the stage which will be reached when the Federal Reserve Board's Index of Industrial Production (unadjusted) has averaged 145 for two months. In this stage we shall require the following steps:

1. Further credit and term restraints upon durable consumer goods purchases and nonessential personal loans.

2. The encouragement and expansion of individual, industrial, and governmental reserves in cash or its equivalent. This we may accomplish through:

   a. Personal savings, induced by the active promotion and sale of government savings stamps and bonds of small denominations—stamps and bonds which serve the additional purpose of providing the people at large with a means of sharing in the financial support of our national defense effort;

b. Increases in the amounts of payment, the extension of coverage, and the extension of the time period under our unemployment insurance laws;

c. Increases in the amounts of payment and the extension of coverage under our social security laws;

d. Medical and hospitalization insurance on a national scale for the people of our country whose insufficient incomes do not permit them to purchase this protection from private organizations.

(As I propose larger commitments under our unemployment and social security laws as a socially desirable form of accumulation against adversity, and as I invite the initiation of a national insurance plan to cover medical and hospitalization expenses for the underprivileged, I at the same time propose that all these activities be jointly supported by contributions from every individual prospective beneficiary under these plans, by all employers, and by the government.)

3. Drastic curtailment of all governmental activities, expenditures, and loans connected with all nondefense purposes in the conventional field of private enterprise.

4. Restraints on business expansion loans for nondefense purposes.

5. Taxation for reduction of the national debt.

6. Finally, the diversion of the major portion of sales promotion and advertising expenditures to the speculative promotion of pioneer products.

Here the catalog of requirements of the "backlog-building stage" is concluded.

FINAL STAGE—ULTIMATE CHALLENGE TO FREE ENTERPRISE

And now I come to the final stage—the stage when the private enterprise system will meet its most serious challenge, and therefore the stage which we may very consistently call the "free-enterprise-system-challenge stage". This is the period after the Federal Reserve Board's Index of Industrial Production (unadjusted) has declined—mark this word *declined*—to an average of 150 for two months.

Then, indeed, at a time when our future economic security will be at stake, we must call upon all of our vision and imagination; upon all of our resources; upon all of our ingenuity; and, above all, upon the same deep sense of service that now motivates us, as we move forward in providing the materials for our physical security; to the end that all employables will be kept employed, and that the preponderant majority will find employment on the payrolls of the private-enterprise system.

With these thoughts in mind, then, the following steps represent the needs in this most critical stage—the "challenge-to-free-enterprise stage":

1. Here I submit in all seriousness, as a first step: prayer, and the wholehearted practice of the Golden Rule. And this, I hardly need say, is a continuing, compelling, and comforting requirement; and, happily, that fact is gaining greater force with each passing day as a bedeviled and bewildered world seeks the solace of Divine inspiration from the source of all righteousness and all human rights.

2. Passing from the sublime to the specific: credit and term expansion.

3. More goods and more services for more people at less cost. First of all, more and better housing for more people at a price they can afford to pay. Then more and better furnishings of every kind for these houses, to the end that, within the means of their occupants, these houses may be converted into comfortable, convenient, and happy homes. Then, more consumer goods of every character at lower cost. And, finally, low-cost distribution as a means of filling the people's wants at the least possible cost. Of course, more goods and services for more people at less cost is another continuing necessity.

4. Intensive sales promotion and advertising.

5. Intensification of industrial and utility modernization.

6. Conversion of surplus defense plants, on private property, to the production of goods for the normal needs of the nation.

7. And, finally, permanent government public works.

PRIVATE INITIATIVE—"OR ELSE. . ."

With this outline of the requirements of our most challenging stage, I conclude my presentation of the stages and steps—with the reminder that, as hereinbefore stated, all of the foregoing is an attempt first to present a *realistic* view of the forces underlying the world conflict, and then to provide a *specific basis for discussion*, to the end that, together, we may find the way best to insure our moral, physical, and economic security; the total security I feel we must have if, amidst the destructive forces flooding the world with false philosophies, the democratic process and the American free-enterprise system are to be preserved in their most useful form.

This, then, leaves only a suggestion pertinent to an earlier statement that "the components of the private-enterprise system should take the initiative in defining the obligations the whole system can and will positively assume, while collaterally and co-ordinately it defines those obligations which it will actively support government in assuming". This proposal is that, with this whole presentation as a starting point, public-spirited leaders in finance, in industry, and in commerce consider what kind of a program they can develop, for which they can gain the wholehearted support of those elements representing 70 per cent of the financial, industrial, and commercial power of the private-enterprise system. Then, having established the obligations of business, the manner in which these obligations would be discharged, and the manner in which business would exercise internal self-discipline, they should urge equally enlightened leaders in labor and agriculture to proceed to the same end. Then, finally, after all factors have reconciled their differences and reached an agreement upon the responsibilities they would jointly discharge, government (the servant of all of the people) could have a clearer definition of the public service the free-enterprise system could definitely be relied upon to supply. And, collaterally, government could constructively be presented with a clear definition of the province within which it could operate in the common interest, with the firm and full support of all elements of the private-enterprise system as well as with the support of the general public.

This suggestion is made with a deep realization of the difficulties involved—but it is made also with a comprehension of the fact that the private-enterprise system is faced with two alternatives: Either *private* decisions will be made and enforced by public-spirited and fully supported leaders in finance, industry, commerce, labor, and agriculture, *or public* decisions will be made and enforced

by the government of the whole people for the whole people. Therefore, it must be seen that if no way can be found to make and enforce the first kind of decisions, there can be little justification for resistance to the second kind.

And at this point let us recall to mind the lessons of history. The Magna Charta was the work of a few wise and courageous men whose minds and hearts were brought into concord by their common zeal for service in the common good. This, too was true of our own Declaration of Independence and of our cherished Constitution. Yes, these historic guides to greatness were the work of a few men whose words and ideas, falling like a pebble in the center of the pool of world thought, set up ever-widening circles of agreement and support. Now, as I propose that a few wise and courageous men from the ranks of free enterprise—whose minds and hearts are in concord because of their common zeal for service in the common good—get together for the purpose of composing a constitution for the free-enterprise system, I remind you of the process whereby progress is made.

"AWAKE—ARISE—OR BE FOREVER FALLEN"

And as I do so, I also assert that it is the duty of the American free-enterprise system fully to recognize the advent of a new and dangerous era, and, recognizing that fact, to adjust itself in a manner which will permit it to exercise freely its full potentialities for service to the public, while preserving its entirely consistent purpose of producing a profit.

The call to the people who comprise the American free-enterprise system today is the call that all Americans must heed, no matter what their walk of life may be. It is a call best expressed in the words of John Milton, recently quoted by a famous American editor. Milton's cry was: "Awake—arise—or be forever fallen".

As I here repeat that challenging call to you, I am certain that we shall meet it; and I shall conclude this lengthy presentation with a statement of the conviction upon which this feeling of certainty is based.

First, I am completely confident that, notwithstanding the difficulties and dangers before us, the public-spirited citizens who preponderantly comprise the American free-enterprise system will see in this new era not an occasion for disheartenment and despair, but rather, an inspiring and challenging opportunity to regain both the full faith of the common people and the cordial, constructive support of the servant of *all* of the people: the Government of the United States.

Further, it is my firm conviction that my enlightened associates in industry, commerce, and labor will seize this challenging opportunity with a clear, deep, and broad conception of the social obligations of the American free-enterprise system—the system upon which all of us rely in some way or another, no matter what our occupation may be. Holding this conviction, I am equally certain that with this complete comprehension of our opportunities, of our obligations, and of the character of the challenge confronting us, we shall all play our full part earnestly, enthusiastically, and effectively.

Finally, my most positive and most comforting conviction is that, as we thus play our full part in sustaining the dynamic character of our democracy, we shall have the soul-stirring satisfaction of knowing that we have done our full duty, the duty of providing our noble nation with the solid foundation of moral, physical, and economic security—the solid foundation of total security upon which we, as a free, friendly, and united people shall continue courageously to construct an ever greater and grander America.

Electric Ship Lighting 60 Years Old

THE year 1940 marked the 60th anniversary of the lighting of steamships by electricity, and even though the first commercial installation of a marine lighting plant in 1880 saw oil lamps standing by in case of failure of the new-fangled power plant, that original equipment, designed, built, and installed by Thomas A. Edison, saw active service for over 15 years with only minor changes and repairs. (See picture, page 127.)

This first and historic power plant for steamships was installed on the steamship Columbia, built for the Oregon Railway and Navigation Company by John Roach at Chester, Pa., in 1879. Early in 1880, the vessel docked at New York to be fitted out for its trip around Cape Horn. The electric light plant was installed at that time. It consisted of three 100-volt constant-potential dynamos constructed at Edison's laboratory in Menlo Park, N. J. Each dynamo was capable of supplying 60 16-candlepower lamps. A fourth dynamo, used to excite the others, was run at half speed.

Edison thoroughness was in evidence in controlling switches, insulation consisting of rubber tubing over the paraffin-cotton-covered wire where it passed over metal, and a generous supply of safety devices such as cutouts and fuses. Original sockets were of wood, suspended by the supply wires to avoid shocks which might break the fragile glass chambers. Lights in the staterooms were controlled by the steward from outside. All fixtures were so arranged that oil lamps could be substituted quickly should the electric power system fail.

The ship sailed from New York in May 1880, carrying 13 locomotives, 200 cars, and other equipment. In a letter to Mr. Edison, dated February 24, 1882, John C. Henderson, the advising engineer of the Oregon Railway and Navigation Company said, "On the night of the 2nd of May, 1880, we started up the dynamos and from the time when the steam was first turned on until the present, they have worked to our entire satisfaction under all circumstances."

The plant served a long period of usefulness. It was not until July 1895, after more than 15 years of continuous operation without repairs, except for minor details, that it was taken out when the ship was overhauled and a plant of more modern construction installed in its place.

George Ashley Campbell—Edison Medalist

"IN RECOGNITION of his distinction as scientist and inventor, and for his outstanding original contributions to the theory and application of electric circuits and apparatus" the Edison Medal for 1940 was presented to Doctor George Ashley Campbell, retired research engineer of the Bell Telephone Laboratories, at a special session of the AIEE 1941 winter convention, Philadelphia, Pa., January 29. Highest award of the Institute, the Edison Medal is presented annually to a resident in the United States of America or its dependancies, or of the Dominion of Canada, for "meritorious achievement in electrical science or electrical engineering or the electrical arts."

At the presentation ceremonies, L. W. W. Morrow (A'13, F'25) chairman of the Edison Medal committee, briefly outlined the history of the award; and AIEE Past President Frank B. Jewett (A'03, F'12) spoke on the contributions and personal qualifications of the medalist who has been his "associate and friend for more than 35 years." Following Doctor Jewett's remarks, AIEE President R. W. Sorensen (A'07, F'19) who presided over the ceremonies, presented the medal and certificate to Doctor Campbell.

Essentially full text of Doctor Jewett's address and Doctor Campbell's response follow on this and succeeding pages.

Qualifications of the Medalist

FRANK B. JEWETT, Past President AIEE

THE QUESTION as to how old the application of science to industry is I do not propose to ask, for attempting to answer it might prove tantamount to trying to pick a date so early that no one else could think of an earlier one. But while the date of the first application of what we might reasonably denote as scientific knowledge to practical affairs is undoubtedly lost in antiquity, the date at which industry first realized the practical importance of scientific knowledge sufficiently clearly to go out in active search of such knowledge, is surprisingly close at hand. In fact, I think I should be committing no great exaggeration if I said that it falls within one man's active life, and that man our 1940 Edison Medalist.

I do not say that American industry was the first industry to organize itself for the discovery and application of such knowledge as would be particularly useful in its chosen field; certainly I do not wish to imply that the laboratory which George Campbell joined back in 1897 was the first industrial laboratory of applied science. But it was certainly one of the very earliest, and I have no fear of being contradicted when I say that the venture upon which he embarked was to carry him into what was then an utterly uncharted sea. Indeed, to most people at the time, it appeared not only uncharted, but decidedly threatening. To many it was absurd and some even were frankly hostile—just why I never knew.

I seriously question whether today, with a long record of success behind, those who themselves were not among the pioneer contingent can really appreciate the courage and adventurous spirit which the undertaking demanded of the early industrial pioneers who risked their hard-earned cash upon efforts spent in trying to add to man's store of physical knowledge. It was one thing to attempt to utilize knowledge already gained, but quite another to spend money upon the winning of new knowledge in the hope that it would prove useful.

In this connection I am continually struck by the nonchalance with which a younger generation of research men utilize the methods, tools, and techniques at their disposal for *their* pioneering as though they had always existed. The fact that they were nonexistent or were serious problems for their own immediate predecessors seems to come as a shock.

And I know firsthand that it seemed to many a particularly wild, fantastic gamble to add a mathematician to an industrial staff and contract to pay him a wage without any commitment on his part that he could make his special language bring new meaning to the work in hand Of course, it is true that the submarine cable problem had yielded years before to Kelvin's analysis, but it was equally well known that the solution Kelvin obtained for that earlier communication problem was of no value to the telephone engineer when it came to making a successful long-distance speech circuit.

Perhaps we get our clearest conception of the fast pace at which science and industry have been moving when we stop to recall what progress has been made within the span of Campbell's active career. Within the domain of industry alone, the few small inquisitive groups of his early years have expanded and grown to thousands of laboratories, some of which employ thousands of workers. We may say truly of our medalist, therefore, that he was a pioneer among pioneers. Not only did he show the courage and fortitude of the explorer when, as a mathematician, he entered a new and untried department of industrial effort, but throughout his long and active life he has won outstanding successes by tackling unpromising situations and literally living with them until he had mastered every difficulty and straightened every devious turning.

In this connection I am reminded that Campbell's undergraduate college training was that of civil engineering. He must have had a good master—indeed, I know he had a good master because it was none other than Professor George F. Swain, then of Massachusetts Institute of Technology and later of Harvard University. In his later work Campbell has certainly exemplified the best qualities of the surveyor by moving, as I have said, into one uncharted region after another, to leave each only after he had completely mapped its topography and

left it a land whose natural resources he had exposed for all those who chose to follow the trails he blazed and to employ the riches he marked with his "section corners" and "witness trees."

I wonder how many realize what a difficult task this is, especially in the atmosphere which industry provides. In the type of mathematical exploration which Campbell has carried on, he has been necessarily and essentially a lone worker. There was no tramp of many feet just behind him. His work was always far out in front of the main column. Industry's greatest efforts usually occur in departments long since fully explored. In other words, Campbell as a pioneer found himself in surroundings where it was peculiarly difficult to "keep his eyes in the boat." His slow and uncertain progress at times, it seems to me, must necessarily have struck discouragement to his heart as he beheld the more commercialized ventures around him forging ahead into production or use and, what may be even more important, into a conspicuous place in the minds of management and the public.

So here again Campbell has proved himself a man of unusual courage. Repeatedly throughout his career he has staked his all upon an issue he alone envisaged and which at best could not reach its zenith of recognized importance till years afterward. It is one thing for the research man who occupies a university position to do this with equanimity, but it is quite another matter for one surrounded as Campbell has been by the impetuous atmosphere of industry, to do it.

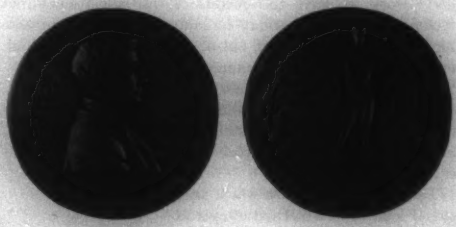
I presume there have been few medal presentations in which most of the time was not spent in reciting the medalist's contributions. In the present instance, such a procedure seems scarcely necessary. Campbell's outstanding discoveries, particularly the loading coil and the electric wave filter, are well known—in fact, have become almost as familiar in modern technical parlance as the electric motor or the internal combustion engine. But strong as the temptation is to describe at greater length the very lovable and laudable personal qualities of the man, I realize that at least passing reference should be made to his outstanding technical contributions.

The first of these was the loading coil for extending the range and improving the quality of long telephone lines as well as for conserving copper. In this field he was not alone. In fact, after final adjudication under the technical rules of the patent law, the basic patent was awarded to Pupin, on the ground of priority of conception. But Campbell, then a young man, did his theoretical and experimental work without any knowledge of the study his rival had in hand. Further, I have no hesitation in saying that Campbell's analysis of the problem was actually more comprehensive then Pupin's. It led him to formulas for the design and spacing of loading coils which were superior, so that from the very beginning of practical application, they alone were employed for building loaded lines in the United States and abroad. By this one piece of work performed within a relatively short time after his employment in the Bell company in Boston, Campbell demonstrated his unique ability at mathematical physics, as well as his knack for stating conclusions in a form that the development engineer could use in practical applications.

To review the history of loading and the immense benefits which it conferred, not alone on the infant art of telephony as it existed at the time, but even more upon the highly developed art as it exists today, would carry us too far afield. However, there is one not generally appreciated aspect of loading which merits mention here.

With the introduction of loading, inductive effects resulting in the phenomenon of crosstalk between neighboring telephone circuits were more evident, and coping with them became more of a problem for the telephone engineer. So, too, did the effects of insulation.

While it had been shown by earlier workers that crosstalk was a complex effect of both electromagnetic and electrostatic induction in which the latter was frequently the more important, I believe Campbell first reduced the various factors to such a computational basis as was both accurate and readily manageable. He pointed out the importance of Maxwell's capacity coefficients and coined the term "direct capacity," now modernized to "direct capacitance." He showed in these early memoranda



The Edison Medal, highest award of the AIEE

The medal was founded by associates and friends of Thomas A. Edison, who desired to commemorate the achievements of a quarter of a century in the art of electric lighting with which Edison had been so prominently identified, and to serve as "an honorable incentive to scientists, engineers, and artisans, to maintain by their works the high standard of accomplishment" that had been set by Edison. AIEE was invited to undertake the responsibility of making the award, and the medal was established on February 11, 1904. Awards of the medal have been made to the following:

1909 Elihu Thomson	1925 Harris J. Ryan
1910 Frank J. Sprague	1927 William D. Coolidge
1911 George Westinghouse	1928 Frank B. Jewett
1912 William Stanley	1929 Charles F. Scott
1913 Charles F. Brush	1930 Frank Conrad
1914 Alexander Graham Bell	1931 E. W. Rice, Jr.
1916 Nikola Tesla	1932 Bancroft Gherardi
1917 John J. Carty	1933 Arthur E. Kennelly
1918 Benjamin G. Lamme	1934 Willis R. Whitney
1919 W. L. R. Emmet	1935 Lewis B. Stillwell
1920 Michael I. Pupin	1936 Alex Dow
1921 Cummings C. Chesney	1937 Gano Dunn
1922 Robert A. Millikan	1938 Dugald C. Jackson
1923 John W. Lieb	1939 Philip Torchio
1924 John W. Howell	1940 George A. Campbell

that crosstalk between two circuits depends to a considerable extent, and particularly in the case of loaded lines, on a function of the various direct capacities between the wires of the two circuits. He termed this function the "direct capacity unbalance."

Campbell's studies led not only to mathematical formulas but to the development of measuring apparatus which was destined to play a great part in future telephone developments. For it was in this period that he produced his well-known shielded balance for the accurate measurement of electrical constants at telephonic frequencies. It is interesting to remark in this connection that in this early work we have the genesis of the whole shielding technique as applied today in innumerable ways in the high-frequency art. Also, out of it grew a simple method for measuring direct capacitances, as well as capacitance-unbalance test sets which have played a fundamental role in the manufacture, installation, and maintenance of telephone toll cables.

The ancillary problems which arose out of loading as a method of extending economically the range of telephony and whose solutions originated largely in Campbell's powerful intellect are striking examples of a phenomenon many times repeated in the history of telephonic development. The introduction of a new and useful thing demands a more adequate and refined structure in which to function. The getting of this new structure—usually at added first cost—brings in its train elements of greater reliability, better service, and more economical maintenance than the old one possessed. Not infrequently these incidental things, which in themselves might never have presented problems thought worthy of attack, turn out to have equal or greater value than the thing which initiated their solution.

George Ashley Campbell

1940 Edison Medalist

Closely associated with Campbell's analysis of the loaded-line problem, and indeed springing from it, is that of the electric wave filter. This is undoubtedly one of his most important and also best-known contributions. Today in nearly every phase of telephone transmission, as well as in many other departments of electrical engineering, filters play an important part; their future role promises to be an expanding one and one which again is not, by any means, confined to telephony.

Turning to the telephone repeater art which plays such an important part in the modern telephone plant, we again find evidence of Campbell's masterly hand. The type of line balance involved in repeater operation early attracted his attention. The early repeater development involved two problems: first, to secure as nearly as possible a perfect amplifying element; and second, to adapt this element to the telephone line.

What is involved in this second problem can only be appreciated by the telephone engineer who has had experience in the transmission art. Early in the development of telephony it challenged attention. Before Campbell attacked the problem various experimenters and inventors had proposed circuits to accomplish two-way telephony, and out of this prior work had come rather empirically two fundamental repeater circuits, namely, one in which a single repeating element amplifies messages reaching it from both directions, and one which includes two amplifier elements, one assigned to each direction of transmission. These repeater circuits came to be known as the 21-type and the 22-type, respectively. In the 21-type repeater, two sections of line as nearly identical as possible are balanced against each other as opposite arms of a bridge. In the 22-type repeater, each incoming section of line is balanced against an artificial line or network, thus permitting, as Campbell's analysis showed, a greater inherent flexibility as well as a greater stability. The inherent stability limits of these circuits, however, were not clearly formulated until Campbell made a study of the circuits.

In the same memorandum he suggested the use of the "four-wire circuit" as a logical extension of the one-way paths in the 22-type repeater, each extended path containing as many one-way amplifiers and line sections as desired. This was in 1912, and the four-wire circuit, although now so widely used both at voice frequencies and in the carrier art, appeared at that time to have little practical application. It was proposed as a structure possessing very great stability, relative to the other types of repeatered lines, and as such was recognized as of great technical interest, if not of immediate commercial value. It was an example of a technical advance destined to be employed only after a complex art had caught up with it.

Turning to the subscriber's set, we find again the indelible impress of Campbell's mind. He was the originator of the single-transformer anti-sidetone circuit which is now achieving almost universal acceptance. But more than this, he did a masterful piece of work in revealing all of the possible circuit arrangements having doubly conjugate branches, and in setting down the impedance relations of the line, network, transmitter, and receiver for these various branches. This systematic analysis of the problem greatly facilitated a comprehensive survey, giving assurance that all types of circuits were being considered and that those best fitting the best transmitters and receivers available at any time were being selected.

In closing I want to return again to George Campbell, the man, and here I feel that I cannot do better than quote from one of his former colleagues, Doctor E. H.

Colpitts. In writing of Campbell some years ago, he said:

"In common with many other truly great minds, it has been his choice to avoid publicity and public appearance, so that outside the circle of his immediate associates and a few of the more mathematically gifted students of his chosen branch of electrical science, his fame is far from commensurate with his achievements.

"In Campbell's case, lack of participation in public activities must not be interpreted as indifference or lack of interest in the common welfare. He has shown himself in the highest sense to be an idealist, and having once aligned himself with a cause, he has served it devotedly without regard to the toll of effort it might exact from him personally. He has been more than a pioneer and inventor. His mode of life and work has been as much an inspiration as his technical contributions are foundation stones of the telephone art. His self-sacrifice and devotion will long linger in our memories, and his serenity sets a high goal toward which we, in our individual efforts, will aspire but seldom reach. Viewing his long and successful career, we realize anew the profundity of Emerson's declaration, 'the great man is he who, in the midst of the crowd, keeps with perfect sweetness the independence of solitude.'"

To this tribute I should like to add a personal one for the man who has been my associate and friend for more than 35 years. In doing so I will use one word which Colpitts has quoted from Emerson in an even broader sense.

Nothing I could say would add to the distinction of Campbell's scientific accomplishments—they speak for themselves. I can appreciate the results and in a way the scholarly grandeur of the attack. Beyond that I belong among those who follow where he has led.

In one sector of appraisal I yield precedence to no man, however. Here, after more than half a lifetime of association I can sum up that appraisal in a single word. He is in every sense a "sweet" man. I feel certain that in Doctor Campbell we have one who, from every point of view, is a fit recipient of the Edison Medal.

The Pursuit of Curiosity

GEORGE A. CAMPBELL, 1940 Edison Medalist

I DEEPLY appreciate the honor of receiving the Edison Medal for 1940. It is quite impossible for me to understand why I should have been singled out among all the persons who must have been considered by the committee. The only clue which I have discovered came to me in this way.

Last week when taking a walk I happened to pass the Montclair pumping station, and turned in to watch the superintendent who was busy repairing water meters. He explained to me, in detail, the nature of the damages which bring water meters to his bench. I left the pumping station quite elated that I had added to my meager knowledge of this most common instrument with its wobbly disk. This little experience prompted the thought that curiosity was as good an explanation of the Edison Medal award as I could find.

My father was an excellent teacher of physics and mathematics, and he did much to stimulate my curiosity about these subjects. It was curiosity which stimulated my study of them in school and college, and which lured me to Europe and on from university to university. When this irresponsible vagabond life would have ended I have no idea, had not my money come to an end, and the remittance arrived from my father for the passage home.

At the age of 27 I awoke to the realization that I had been motivated merely by curiosity in choice of universities and studies, and that I had produced nothing of my own, and had not given a thought to preparation for earning a living.

Curiosity had entertained me for 20 years, but I found no one who was looking for an employee of that description. At length I applied to Doctor Hammond V. Hayes of the American Bell Telephone Company in Boston, Mass., and was given there the first and only permanent job I have had, barring change of place and organization in the Bell System.

In the Bell System I have found the greatest opportunity for the pursuit of curiosity. It was a fascinating field 40 years ago, and during that interval its expansion has been phenomenal, both quantitatively and qualitatively. What was even more important in my own case was that I became a part of a research and development organization with clear-cut goals, high standards of performance, recognition of the importance of the division of labor, and the advantage of teamwork. Doctor Hayes soon assigned to me a theoretical study of transmission on telephone lines and the distribution of currents in telephone networks. For nearly 40 years I worked in this field with the greatest satisfaction. I specialized more and more, and there my training in European universities doubtless asserted itself. In both France and Germany I had been much impressed by the air of thoroughness which pervaded research, and by the fact that few, if any, investigators published papers till they had become well saturated with their subjects. I believe it has been very helpful to me that my curiosity was thus taught to hold itself in check, and not to leave a subject before a reasonably complete survey had been made.

In the Bell organization, I was assigned assistants who could do many things with greater dispatch and efficiency and perfection than I could. To some of these assistants I later reported myself, and others have carried on the work into difficulties which I myself could never have surmounted.

You will see that it is perfectly natural that I am an admirer of that kind of teamwork which represents a division of labor in the intellectual field. At one and the same time it gives a greater opportunity to those whose talents lie within rather narrow fields, and it results in an integrated product greater than the sum of the individual efforts. For reasons I have just explained, I feel that I am a beneficiary of the group method attacking scientific problems. Without the collaboration of innumerable associates, in the Bell System, the contributions you have designated to be mine, I probably should not have succeeded in making. It is a distinct pleasure to me to recall these many associations and to testify that those who have been my colleagues over the years are in large part responsible for the honor of receiving the 1940 Edison Medal.

New Subway Link Completed in New York

Opening of the new Sixth Avenue subway in New York City, December 15, 1940, marked the completion of the most difficult and most expensive subway for its length ever constructed. Although only 2 1/4 miles long, its total cost was approximately $60,000,000. It embodies the latest equipment and practices in the subway art.

ALTHOUGH only 2 1/4 miles in length, and comprising only 7 1/2 miles of track, the Sixth Avenue subway in New York City, which began operation December 15, 1940, is significant for at least two reasons: It involved practically every known type of subway construction at various points along its length; and it embodies the latest equipment and practices in the art. Construction obstacles of unprecedented type and number for so short a line were encountered in the construction of this latest addition to the subway system in New York, with the result that its cost per mile was the highest of any line that has ever been built. The cost of construction, exclusive of equipment, tracks, and station finish, amounted to some $46,800,000; the total cost was approximately $60,000,000.

The line forms an essential link in the so-called IND* Division of the New York City transit system[1,2] for which a route and general plan was adopted by the Board of Transportation of the City and approved by the City's Board of Estimate in 1925. The line was required: (1) to furnish necessary north and south trackage between 53d Street and Christopher Street, at which points it connects with the previously existing system; and (2) to give access from that entire system to the theater, shopping, and business districts contiguous to Sixth Avenue. Construction originally was planned to begin in 1928. However, because tunnel No. 1 of the New York City Water Supply System is built directly under Sixth Avenue for a major part of the distance covered by the new subway, construction was deferred until tunnel No. 2 was completed and in service (1936), on account of the possible hazard to tunnel No. 1 during the construction period due to the use of dynamite in rock excavation.

The completion of the Sixth Avenue line brings the total route miles of the Independent Division to 55.6, and the total track miles to 230.6. Comparable figures for the other two subway and elevated divisions in the City of New York are: IRT Division, 99.3 route miles and 302.9 track miles; BMT Division, 96.0 route miles and 282.1 track miles. The totals for all subway and elevated lines in New York City, therefore, are 250.9 route miles, and 815.6 track miles (including yards). These three divisions, which now are combined under the unification program recently adopted by the City, comprise an electric railway system of no small magnitude. In density of traffic, particularly during morning and even-

Material for this article was obtained partly from the published material indicated in the list of references at the end, and was supplied partly by various members of the Board of Transportation of the City of New York and by the General Electric Company. The generous assistance of all who supplied this material is gratefully acknowledged.

* In June 1940 the City of New York purchased the properties of the old BMT and IRT Subway Systems and renamed them the BMT and IRT Divisions of the New York City transit system, and renamed the former Independent Subway System the IND Division of the New York City transit system.

1. For numbered references, see list at end of article.

ing rush hours, this system ranks second to none.

Among the more significant new equipment installed on the Sixth Avenue subway are the rectifiers which convert the a-c supply to direct current for propulsion of the trains. These are 12-phase units, comprising 12 single-anode tanks of the ignitron type. They are installed in underground compartments adjacent to the subway structure, and are unattended, being operated through supervisory control from a central point from which all substations on the system are controlled. Other equipment is essentially the same as adopted earlier for the Independent subway, the first 12-mile section of which was placed in operation September 10, 1932.

The Sixth Avenue line includes five stations, two of which have side platforms, and three island platforms (between express and local tracks). All station platforms are 660 feet long, except at 34th Street where the east platform is 800 feet long, and the west platform 700 feet. All stations are adequate for the operation of 11-car trains, although present plans call for maximum train length of 10 cars. Complexity of construction of the stations parallels that of the remainder of the line. Direct access is provided from department stores in Herald Square, as well as with the intersecting BMT line and the Hudson and Manhattan Railroad, which terminates just south of 34th Street. At the 47th–50th Street station, direct access is provided to three large office buildings of the Rockefeller Center group. In addition, a pedestrian passageway 25 feet wide was constructed under the center of Sixth Avenue over the subway roof connecting the 34th Street and the 42d Street stations, with entrances to this passageway along Sixth Avenue at 34th, 35th, 38th, and 40th Streets.

CONSTRUCTION

The Sixth Avenue subway involved almost every type of subway and tunnel construction used in New York City—compressed-air shield tunneling, rock tunneling at normal air pressure, and the usual cut-and-cover construction—and many obstacles were encountered in building it.[3] Probably no other subway in New York ever was constructed through a more congested area or required to be built for a distance of $1^1/_8$ miles adjacent to an operating subsurface railroad and throughout its length of $2^1/_4$ miles cross over and under as many operating subsurface railroads as the Sixth Avenue subway. Not only was it necessary to construct this line through one of the most congested traffic areas of the city and under a street unusually congested with sewers, water and gas pipes, telephone, telegraph, and power lines, steam mains, and other subsurface facilities, but the presence of the Sixth Avenue elevated railroad required that 670 elevated columns be picked up, temporarily supported during construction, and finally transferred and supported on the roof of the new subway, practically all of which was performed before the elevated railroad structure was removed. The Sixth Avenue elevated railway structure was privately owned, and authority by the State Legislature to have it removed was not obtained by the City until after construction of the subway has been started. It cost the City about $5,000,000 extra to build the subway under the elevated structure. The removal of the "L" transformed Sixth Avenue from a dismal, noisy, and unsightly thoroughfare into a boulevard, comparable on the west side of Fifth Avenue to what Madison Avenue is on the east.

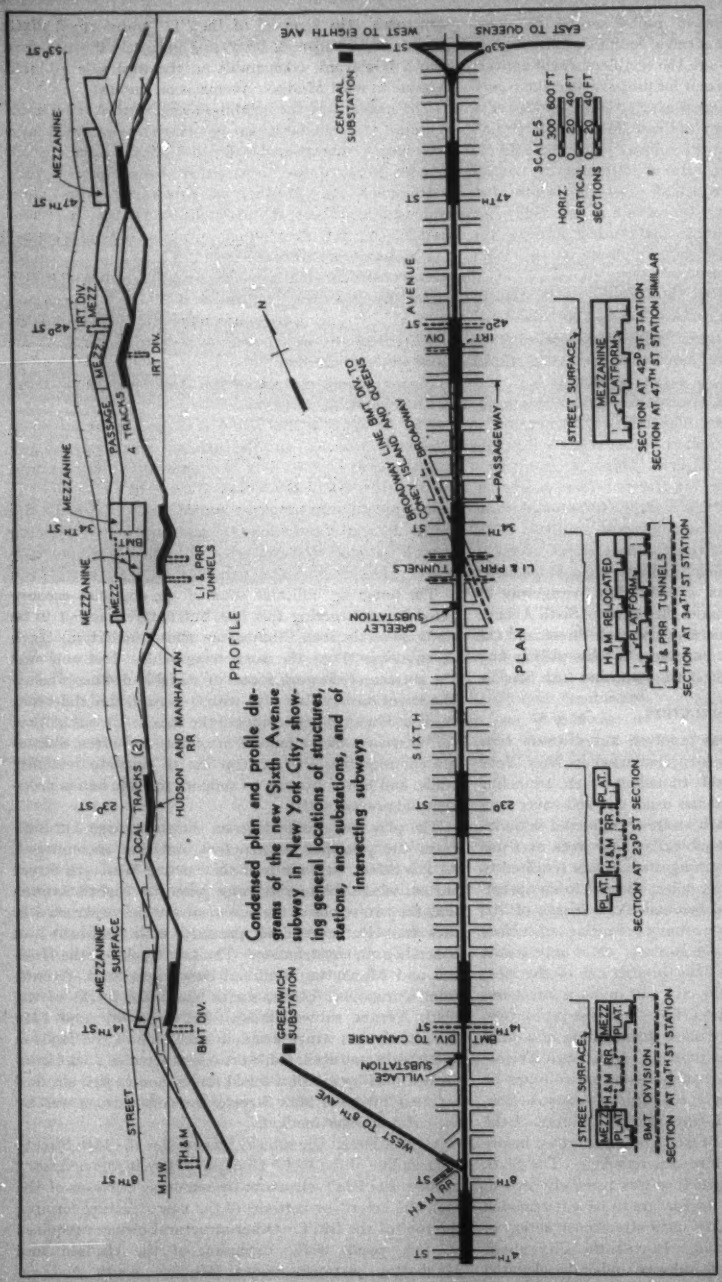
The majority of the buildings along Sixth Avenue were required to be underpinned or otherwise protected, and six existing subway and railroad tunnels crossing Sixth Avenue were required to be either spanned over or tunneled under. In addition, it was necessary to cross under, support, reconstruct, and maintain the Hudson and Manhattan Railroad, a two-track structure extending under the center of Sixth Avenue from 9th Street to 33d Street, while constructing the new subway adjacent to and partly under this structure. All this work had to be performed without interruption of service on the transit lines or undue inconvenience to the vehicular or pedestrian traffic, at the same time maintaining satisfactory facilities to the property owners and patrons of the stores and shops along Sixth Avenue.

The presence of the Catskill Aqueduct under Sixth Avenue between 53d and 33d Streets required unusual care in the use of explosives in the removal of the rock and limited the amount of excavation made in advance of the completed subway structure in order not to remove too much of the rock cover over the aqueduct before replacing it with the steel and concrete of the new subway structure.

The foregoing indicates some of the obstacles encountered in constructing this line, but nature was not to be outdone as the rock (Manhattan schist) underlying Sixth Avenue was about the worst imaginable. Not only was the surface of the rock found at variable distances below the street surface, but also with a considerable difference in elevation on opposite sides of the street. It was blocky, full of seams, badly faulted in places, and often disintegrated, requiring the construction of concrete retaining walls, and heavy bracing to support the side banks properly and prevent slides.

The plan and profile diagram shown on page 112 indicates the principal construction obstacles encountered. At 9th Street, just north of the existing West 4th Street station where the new subway joins the Eighth Avenue line, the two tracks of the new system were constructed in rock tunnel at normal air pressure, with steel-bent and concrete-arch construction. The two tracks of the Hudson and Manhattan Railroad curve into Sixth Avenue from Christopher Street, under which the tracks of the Sixth Avenue subway cross. Between 10th and 13th Streets, the two tracks, one on each side of the Hudson and Manhattan Railroad, were constructed as a cast-iron-lined tunnel by use of a shield under compressed air, and between 13th and 26th Streets, the construction was by the cut-and-cover method.

At 14th Street, the subway passes over the 14th Street–Eastern line of the BMT Division. Here it was necessary to alter the BMT structure by removing portions of the roof, the invert (or bottom) of the new structure forming the roof of the BMT. Other structural changes required at this point were: extension of the Hudson and Manhattan platforms about 100 feet south and re-



moval of a similar portion from the northern end of those platforms, thereby moving the station in a southerly direction about 100 feet; reconstruction of stairways to the BMT structure; erection of new columns for the support of the Hudson and Manhattan and Sixth Avenue structures through the platforms of the BMT station. At 23d Street, it was also necessary to alter the existing Hudson and Manhattan station.

Between 26th and 31st Streets, the surface of the rock is higher, so that the two tracks of the new subway were constructed in a rock tunnel with steel-bent and concrete-arch construction. At 31st Street, the two tracks emerge from the rock tunnels and enter a cut-and-cover section, changing to a four-track structure between this point and 53d Street. Between 31st and 33d Streets, the Hudson and Manhattan structure was removed in order to construct the new subway. Later, the Hudson and Manhattan terminal station at 33d Street was reconstructed. In the meantime, it was necessary to establish a temporary terminal at the existing Hudson and Manhattan station at 28th Street. This required the construction of passageways on both sides of Sixth Avenue and provision for additional entrances at 29th Street. It was also necessary to alter the existing Hudson and Manhattan structure between 29th and 31st Streets, and install signals and equipment to

provide facilities for turning of trains of that road.

At 32d and 33d Streets the subway was constructed over the tunnels of the Long Island and Pennsylvania railroads; in order to provide sufficient space for the construction of the new subway, it was necessary to remove the existing roofs of these tunnels, the invert of the subway structure forming the roofs of the tunnels.

At 34th Street, Sixth Avenue intersects Broadway at an angle of some 20 degrees, under which is located the Broadway line of the BMT subway. Probably the most difficult piece of construction was the portion of the new structure directly under this operating subway, which required that the BMT structure be supported without interruption to service. At 41st Street, the Sixth Avenue subway passes over the IRT Queensboro subway, a two-track line built in rock tunnel. In order to construct the new subway, it was necessary to remove the roof over the Queensboro tracks, with the invert of the new structure forming the roof of the Queensboro line. Under 42d Street is the old IRT shuttle which is used for heavy transfer traffic between Grand Central station of the IRT East Side line and the Times Square station of the IRT West Side line. The new subway was constructed under this shuttle line. Here again, in order not to have an excessive grade between 41st and 42d Streets, it was necessary to remove the concrete invert of the shuttle structure, and construct the new subway with its roof forming the invert of the shuttle. This work was performed without interruption to shuttle train service.

Between 43d and 45th Streets, the rock surface was high and all tracks were constructed in rock tunnel. Between 46th and 51st Streets, the four tracks are at the same level and were constructed in open cut under decking. An interesting and intricate layout of tracks extends northward from 51st Street. Four tracks connect with the existing tracks under 53d Street, two curving eastward toward Queens, and two westward toward Eighth Avenue; the other two tracks are dead ended, being provided for a future extension along Sixth Avenue and under Central Park to Harlem and the Bronx.

MAINTENANCE AND RESTORATION OF SUBSURFACE STRUCTURES

In the construction of the Sixth Avenue subway, the maintenance and restoration of subsurface structures presented many difficult problems. A preliminary survey showed that the whole width of the avenue from curb to curb, and in some places the area under the sidewalks, was congested with structures either owned by various utility corporations, or under the jurisdiction of various city departments. For example, at the intersection of 40th Street, were: 15 gas mains ranging in size from 4 to 12 inches; five water mains varying in size from 12 to 48 inches; a 16-inch steam main, occupying a space of more than four feet square; 20 duct banks, comprising about 250 ducts, carrying power, lighting, telephone, and signal cables; and 14 manholes, each ten feet square, and from eight to ten feet deep. To restore all these structures within the limited space between the top of the subway roof and the street surface was the problem.

The procedure usually followed was to place the largest and most important structures into key positions, at the greatest depth of cover over the subway roof, and to restore the other structures around these key positions. Generally, it was possible to do the greater part of the restoration work under the street-surface decking, without interfering in any way with the flow of traffic in Sixth Avenue. At the intersecting streets, however, where structures were most congested, and at some other locations, it was necessary to remove part of the decking. In a few instances, vehicular traffic had to be diverted temporarily into adjacent streets.

Maintenance and restoration of the sewers presented a particular problem. Of all the subsurface structures and utilities the sewers are the least flexible because a continuous downward gradient is required for gravity flow. In many instances, the sewer structures must be built into some portion of the subway structure.

The cost of restoration, by-passing, and other work connected with subsurface structures (not including sewers) varied from approximately 7 per cent of the total cost of the subway structure in the southerly part of the new subway to about 13 per cent in the northerly part. It is interesting to note that the time consumed in the restoration of the subsurface structures was practically equal to that required for the building of the subway structure itself.

ROLLING STOCK

Cars and associated equipment being used in the Sixth Avenue subway are similar to those already in use on the Independent Division.[4] The cars are 60 feet long, 10 feet wide, and 12 feet 2 inches high from rail to roof.

Construction view showing method of supporting columns of elevated railroad, which was not removed until most of the subway structure had been completed

View showing method of supporting the many subsurface structures during construction of the subway

Seats are provided for 60 passengers and are arranged in four groups, in effect dividing the space within the car body into four equal sections, each served by a pair of doors on either side of the car. The total weight is 84,300 pounds; this weight, which is relatively low for a car of this size, was kept down by liberal use of aluminum and by concerted efforts on the part of various equipment manufacturers. The design of these cars was adopted after careful study of both the equipment being used on the older two subway divisions in New York and many proposed new designs, by a joint committee consisting of engineers of the Board of Transportation, and representatives of the other rapid transit systems and of car equipment manufacturers. A model car was first constructed in the office of the Board of Transportation and thereby became a sort of laboratory for car design and specifications.

All the cars are motor cars, no trailers being used on the Independent Division. Each car is driven by two 190-horsepower motors, both mounted on one truck. The second truck of each car is a trailer. All wheels are equipped with clasp-type brakes.

Control equipment is grouped in a permanent cab at each end of each car. Multiple-unit electropneumatic control makes it possible to run a train of from 1 to 11 cars from a single position. Control is of the automatic battery field type, with acceleration set at the rate of 1.75 miles per hour per second; this rate of acceleration is maintained regardless of load. The operating coils of the line switch are actuated by trolley current so that the main motor circuit is opened immediately on loss of power, but the multiple-unit control is operated from a low-voltage storage battery. Braking also is controlled automatically at the rate of 1.75 miles per hour per second.

Lighting of the car interior is obtained from 22 incandescent automatic-cutout lamps in series, each lamp taking 1.6 amperes at 30 volts. These lamps are set in short-circuiting sockets. Four battery emergency lights per car are switched on automatically whenever trolley current is interrupted.

Heating in winter is furnished by electric underseat heaters, and ventilation in summer by five horizontal four-blade electric fans mounted on the ceiling. The car lamps, heaters, ventilating fans, and destination signs have their circuits so arranged that they can be controlled from the motorman's position at the head of the train. Door control is arranged for multiple unit operation, the front half of the train (up to a maximum of six cars) being controlled by the conductor, and the rear half (five cars or less) by the guard. A total of 26 train-line wires through the electric couplers carry battery current for the control of motors, brakes, door engines, lamps, fans, heaters, and destination signs. The use of automatic couplers facilitates the coupling and uncoupling of cars.

PROPULSION POWER SUPPLY

For propelling the trains of the Sixth Avenue subway, d-c power at 625 volts is supplied from four substations (see page 112), which in turn are supplied from the 60-cycle system of the Consolidated Edison Company, as are all substations on the entire Independent Division. Conversion equipment for the new line has been installed in these four substations as follows:

Central substation—2 4,000-kw synchronous converters
Greenwich substation—1 4,000-kw synchronous converter
Village substation—2 3,000-kw mercury-arc rectifiers
Greeley substation—2 3,000-kw mercury-arc rectifiers

Two additional 3,000-kw rectifiers were installed at other points on the system.

The synchronous converters were installed in the two existing stations to operate in conjunction with units already installed. The additional machines brought each of these two substations up to a total of four 4,000-kw converters each. The two rectifier substations are new underground structures built in conjunction with, and adjacent to, the subway structure.

The addition of these units to the conversion equipment of the Independent Division adds a capacity of 30,000 kw, making the total system capacity now 326,000 kw; of this total 65,000 kw is in synchronous conversion equipment, and 261,000 kw in rectifiers. When the Independent Division first was planned, it was expected that synchronous converters would be used throughout.[5] Later, however, the mercury-arc rectifier was developed to the point where it became available for this purpose. Consequently, only five synchronous-converter substations were built for the Independent Division, the remainder being mercury-arc rectifier stations. With six exceptions, all

the latter are underground, being housed in structures adjacent to the subway structure.[6,7]

All substations, both synchronous-converter and rectifier, on the Independent lines are unattended, with control from a central power dispatcher's office in 53d Street. The new substations on the Sixth Avenue line require only additional panels on the control board in that office. Normally, the rectifiers are placed in service and taken out of service by supervisory control.[8] After the starting impulse has been given from the power dispatcher's office, the operating sequence is entirely automatic, protective devices checking the operating conditions before a unit is connected to the bus. If, during the operation, some abnormal condition that could correct itself should occur, an automatic protective device will take the unit out of service; as soon as the condition is corrected the unit automatically will return to service without further attention by the operator. If some abnormal condition necessitating maintenance work should occur, the unit will remain out of service until the trouble has been corrected.

The number of d-c feeders per station depends upon the third-rail arrangement. The four third rails are sectionalized at alternate substations. At substations where the rails are sectionalized, each rail end is fed through a separate feeder circuit breaker, resulting in an arrangement of eight feeders. At the alternate substations where third rails are not sectionalized, the four third rails are tied together through the substation bus, requiring four feeders. All d-c feeders on the system are controlled by 3,000-ampere high-speed circuit breakers, each of which can be opened or closed by supervisory control from the dispatcher's office. Factory-assembled units are used throughout the substations for the control and protective equipment.

Control of the synchronous-converter substations is similar to that of the rectifiers.[8] Machines may be started and stopped from the power dispatcher's office, all operations in the starting sequence being automatic after the initial impulse is given. All operating conditions are checked automatically before a converter is connected to the bus. In these substations, one unit is kept running continuously. As the load increases to a point where one machine cannot carry it satisfactorily, a second machine automatically will start and be connected to the bus. Further increases in load will cause additional machines to be started. The operating sequence is set manually, and changed frequently. Should one machine fail to be connected to the bus, because of some faulty operating condition, the machine will shut down, and the next one in the sequence automatically start.

All d-c feeder cables are 2,000,000 circular mils in size. These cables terminate at cast-copper connectors in insulating housings adjacent to the rails; from these connections, 500,000-circular-mil cables extend to the third rails.

Short-circuit and overload protection is provided for each feeder. After a feeder circuit breaker has opened, the resistance of the feeder is measured automatically. If the measured resistance is 0.3 ohm or more, the breaker will reclose; if less than 0.3 ohm, the breaker will remain open until the resistance increases or until the feeder is locked out by a timing relay after remaining open continuously for several minutes.

Power for the control operations is supplied by 60-cell lead storage batteries installed in each substation. These are "floated" across a shunt-wound generator, which is driven from the low-voltage a-c network supply.

THE NEW RECTIFIERS

The rectifiers installed in the Village and Greeley substations are of the ignitron type, which consists of a separate tube or tank for each anode circuit. The selection of this type of rectifier was based on successful operation of similar equipment previously installed at 143d Street in Queens.

This type of rectifier has many advantages for rapid transit service. First, it has very high operating efficiency. This is inherent because of the relatively short arc stream between cathode and anode as compared with the multianode type of rectifier. A second advantage accrues from the fact that the ignitron is made up of an assemblage of individual tubes. If any of the tubes fail other tubes may readily be substituted. This would tend to reduce the outage time of a rectifier resulting from failure or breakage of any of the major parts. Third, the single-tube type of rectifier is easier to cool because tube dimensions are small and copper tubing may be brazed to the outside of the tank to provide the necessary cooling. The fourth point of advantage is that, being made up of a number of small component parts, these rectifiers are easier to handle in the limited space of small underground substations.

The rectifiers on the Sixth Avenue line consist of two rows of six tubes each, mounted on a steel framework. The vacuum pumping apparatus is located at the center of the structure, and vacuum manifold and water manifold are mounted between the two rows of tubes. The vacuum manifold is water-cooled and is provided with a mercury trap at each tube location. The water manifolds are run at the top and bottom of the tubes and cooling water is supplied to the copper cooling coils of each of the tubes in parallel. Each tube is equipped with a manually

Interior of one of the newest cars in use on the Independent Division of the New York rapid transit system, with seat upholstery of plastic material; note subdivision of car into four sections, each served by a pair of doors on either side

operated vacuum valve. If it is necessary to remove a tube, closing all these vacuum valves would prevent losing vacuum in the remainder of the tubes.

As each tube is equipped with a copper cooling coil, there is no necessity for using treated water to prevent corrosion. The customary heat exchanger which is used with multianode tanks therefore is omitted; and although a recirculating scheme of cooling is used, this merely consists of a pump which forces water rapidly through the cooling pipes insuring uniform temperature distribution throughout the length of each tube and uniform flow through all of the tubes. The necessary raw cooling water to hold the proper temperature is admitted from the city mains as required. Surplus water overflows to the sump.

The rectifier tubes are made up of seamless steel drawn cylinders closed at one end and with a flange added at the other end to accommodate a cover. The mercury of the cathode is placed at the bottom of the tube, and as the arc is not continuous while the tube is operating, no cathode insulation is required. A steel separator around the outer edge of the mercury pool serves to catch dirt and particles of material washed down on the sides of the tube. The igniter which dips into the center of the mercury pool is carried by an insulated rod fastened to a flexible diaphragm mounted on a flanged opening in the side of the tank. Adjusting screws are provided so that the immersion of the igniter in the mercury pool may be accurately controlled without breaking the vacuum. Above the cathode is a baffle to prevent mercury splash from the cathode being carried to the anode. The anode and the anode baffle are mounted on the detachable cover, and both are constructed of graphite. All electrical circuits enter the vacuum chamber through Mycalex insulators.

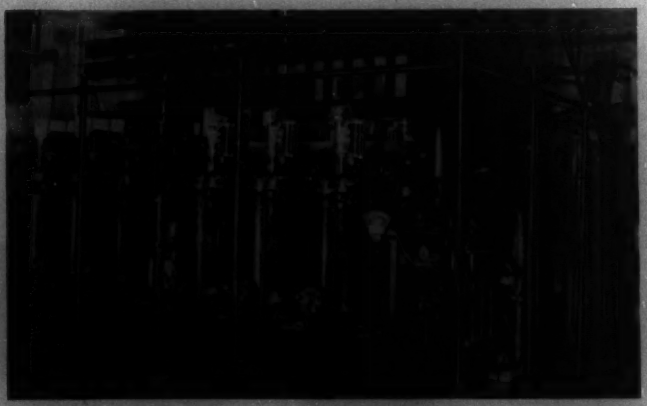
The operation of the ignitron type of rectifier has been described in a number of technical papers.[9,10] There are, however, various means of controlling the igniter circuit. In the present case, the capacitor type of firing circuit is employed. This circuit employs a transformer for supplying the necessary power to the igniter circuit with correct phase relationship, a capacitor which is charged from this transformer, an auxiliary vacuum tube for releasing current to the igniter at the proper point in the cycle, and limiting resistors. It is necessary for the igniter to fire and start the power arc each cycle. At the end of the tube conducting period the main arc goes out and no other arc exists within the tube until the arc is again started when the main anode again should start to conduct.

The necessary firing equipment consisting of auxiliary vacuum tubes, capacitors, resistors, supply transformers, and a voltage regulator is mounted in a separate cubicle. The voltage-regulating equipment insures proper excitation through a range of supply voltage from 20 per cent below to 10 per cent above normal. The auxiliary vacuum tubes are mounted in two rows of six in the cubicle and "bull's-eyes" in the cover over the tubes provides visual indication on the operation of all tubes.

The quadruple zigzag 12-phase transformer connection is used to supply power to the rectifier. This connection uses two 180-cycle interphase transformers and one 360-cycle interphase transformer.

A relay gives indication over the supervisory system at the dispatcher's office in case of failure of one of the ignitron tubes to fire properly for any cause. This failure might be caused by a faulty igniter or a defective auxiliary vacuum tube. The rectifier may operate with 11 anodes firing, or may be shut down by the dispatcher, as he prefers. Operation on 11 anodes causes considerable distortion in the a-c supply and in the d-c output. Therefore, it is preferable to correct this condition as soon as possible. Provision is made to facilitate a rapid change from 12-phase operation on the complete transformer to 6-phase operation on half of the transformer. This may be accomplished by simply removing six of the fuses from the firing circuit. The rectifier may be operated indefinitely at half its rating using the 6-phase connection.

Other equipment in these stations follows very closely the practice of previous New York Board of Transportation installations. High-voltage a-c circuits are completely enclosed with metal-clad switchgear. Control panels are all of the cubicle type.



One of the four 3,000-kw 625-volt ignitron-type rectifiers installed to furnish propulsion power for the Sixth Avenue subway; each of the 12 tanks of this 12-phase rectifier contains a single anode

THE NEW CONVERTERS

The 4,000-kw synchronous converters installed on the Independent System in 1930 are said to have been the largest 60-cycle converters built for railway use up to that time.[5]

The highly satisfactory operating record of these machines led to the selection of the same type of unit for the increased capacity required in the Central and Greenwich substations. However, operating experience and progress in the art have suggested several improvements which have been incorporated in the new machines.

The earlier machines were equalized at the commutator end of the armature, once for each armature slot or once every four commutator segments. The new machines also are equalized at the commutator end, but have an equalizer connection for every commutator segment. This increase in equalization will still further improve commutation and short-circuit performance.

The brush rigging used with the previous machines employed fiber insulating collars and sleeves for insulating the brush bracket arms from the supporting yoke. This construction provided adequate insulation and mechanical strength; but as the fiber changed due to changes in humidity and temperature conditions, occasional tightening of the supporting bolts was required. Molded Mycalex insulators are used in the new machines, simplifying the construction and at the same time providing strong permanent insulating joints. Mycalex insulators are not affected by humidity, have smooth surfaces which do not collect dirt, thus maintaining good creepage insulation, and are very resistant to the action of an electric arc.

Another innovation in the new converters is the elimination of the pilot brushes. Converters of this type are started with the main brushes raised off the commutator. Pilot brushes are left in contact with the commutator during the starting period to supply an indication of polarity and to provide current for exciting the shunt field. Before the converter reaches synchronous speed, the voltage between commutator segments short-circuited by the pilot brushes varies continuously with the slip position of the armature, and as a result considerable short-circuit current circulates between these segments through the brushes. This causes the familiar flashing and sparking of these brushes during the starting period, resulting in burning of the commutator and rapid wearing of the brushes. This sparking may also result in throwing small particles of material over the adjacent main-brush tracks in the commutator, resulting in a loss of commutator film and possible poor commutation from the main brushes. Synchronous-converter commutators often are ground or turned solely because of the burning caused by the pilot brushes during starting.

The elimination of the pilot brushes necessarily involved a change in the starting sequence of these automatically controlled machines. The starting sequence with pilot brushes is normally as follows:

1. Apply starting voltage to converter slip rings (main brushes off the commutator).
2. Obtain an indication of synchronous speed by the appearance of voltage across the pilot brushes.
3. Separately excite the converter shunt field for a definite time to insure polarity.
4. Remove separate excitation and make field self-excited, using current supplied from the pilot brushes.
5. Transfer from starting voltage to full voltage on the converter rings.
6. Place main brushes on the commutator.
7. Connect converter to d-c bus.

It may be noted that machine potential as supplied by the pilot brushes is used in operations 2 and 4. This potential is also used for a number of checks during starting sequence.

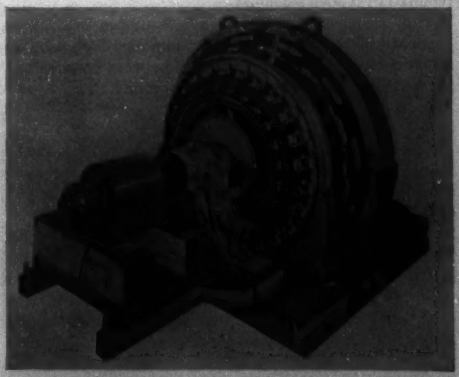
When the pilot brushes of the converter are eliminated the starting sequence must be correspondingly changed:

1. Apply starting voltage to the converter slip rings (main brushes off the commutator).
2. Indication of synchronous speed as determined by a reduction in starting current.
3. Separate excitation of the converter shunt field.
4. Transfer from starting voltage to full voltage on the converter rings.
5. Place brushes on commutator.
6. Change from separate to self-excitation.
7. Connect the converter to the d-c bus.

Adequate time delays and checks are used at various points, as required, in either sequence.

With the present machines the separate source of excitation is the 125-volt substation control battery. The converter shunt fields are divided into two parts which are supplied in multiple from this source.

Another interesting feature of these machines is the method of ventilation employed. The armature and field frame of each unit is enclosed in a volute housing. The armature acts as the impeller of a blower. Air is taken in through the armature spider and discharged to



One of the three 4,000-kw 300-rpm 625-volt 60-cycle 12-phase synchronous converters installed in existing substations to supply propulsion power for the Sixth Avenue subway

Coupled to the left end of the machine is the newly designed armature turning gear to expedite inspection and repair of armature and commutator. Shown also is the barring gear by means of which the armature may be turned by hand by inserting a bar in one of the holes of the disk attached to the shaft at the left end of the armature spider, and exerting pressure against the fulcrum mounted on the side of the bearing pedestal

From this board in the central power dispatcher's office are controlled all substations on the entire Independent Division of the New York rapid transit system, including those newly installed to serve the Sixth Avenue line

the volute housing. From these housings the air is carried in a duct on the ceiling of the basement to one end of the building. A vertical duct then discharges the air through the roof. With this scheme of ventilation no fans or blowers are required, and in addition recirculation of hot air through the machines is prevented. Forced ventilation of the stations is materially reduced over that required with open machines.

The converters are completely equipped with flash barriers which tend to prevent commutator flashovers by providing a high degree of isolation between positive and negative brushes and from brushes to ground.

SIGNALING

Signaling on the Sixth Avenue line is typical of the latest development in subway signaling under the most congested conditions. Signals are provided for ten-car operation at 90-second headway, with 30-second stops at local stations and 45-second stops at express stations. To maintain this headway, particularly through the congested sections between 34th and 50th Streets, it has been necessary to use the "station" timing feature to a large extent and add signals accordingly. The station timing feature provides means to permit trains to follow into stations, at reduced speeds, with reduced braking distance between trains without loss in safety. Also there are sections where "grade" timing is necessary, because of the relatively steep grades and sharp curves. The grade timing feature provides that trains must run at a predetermined speed on descending grades and at other points where excessive speed would create dangerous conditions.

The Independent Division signaling is of two basic types: electropneumatic and all-electric.[11,12] The essentials of both are the same, in that a train shall be protected by braking distance between it and the preceding train at all times, and in that through interlocked switches a completed route for a train, once set up, shall be held by an approaching train, and all conflicting switches and signals locked, until the train has passed completely over that interlocked section of track.

The chief differences between the electropneumatic and the all-electric systems are that air at a pressure of approximately 60 pounds per square inch controlled by electromagnets is used to operate the switches and automatic train stops of the electropneumatic system, while electricity exclusively is used to control and operate the switches and stops of the all-electric system. A 2-inch air line with compressors and automatic air-pressure control is incidental with the electropneumatic system, and a 130-volt storage battery and rectifiers with the all-electric system. Other minor differences exist on account of the different design of the interlocking machines and controls, such as the use of battery indication with the electropneumatic switch to show that the switch operated and locked up properly; and a dynamic indication on the all-electric switch.

Track circuits are of the a-c single-rail type, in which one running rail, called the signal rail, is used exclusively for the track circuit. The other rail is used in common by the signal track circuit, and by the propulsion current return circuit. The average length of track circuit is about 400 feet, minimum length being 100 feet, and maximum 1,000 feet.

Automatic block signals are of the "permissive" type where a red light indicates that a train must stop and then proceed prepared to "stop within vision." The automatic stop arm at each automatic block-signal location,

which enforces recognition of stop indication, is automatically lowered by the train stopping at the block signal.

Interlocked home signals are of the "absolute" type where two red lights indicate that a train must "stop and stay." The automatic stop at each interlocked home signal is not lowered by the train stopping at the signal. Interlocked home signals consist of two three-light units, one above the other, with a single yellow-light unit below. The light indications in the upper unit give to the motorman of a train the same information as the regular automatic block signal regarding the condition of the "block" ahead. The lower three-light unit indicates to the motorman by green or yellow lights the route on which the train will proceed. "Green" indicates straight or main route and "yellow" indicates diverging route. The bottom single yellow, designated the "call-on" signal, is sometimes displayed below the two red lights to indicate "stop and then proceed with caution" and "prepare to stop within vision." This call-on indication requires that the motorman operate a top release key, located alongside the interlocked home signal, to lower the automatic stop arm before train can proceed, thus providing co-operation with the towerman in order to pass an interlocking home signal.

Where route selection is not necessary or where the signal does not control passage over switch points or frogs, interlocked approach signals are used in order not to give a "stop and stay" indication of the interlocked home signal. These signals are the same in indication and control as the automatic block signal except that they are lever-controlled from the interlocking machine and mechanically and electrically lock the switch or switches within their control limits.

Two interlocking machines have been installed on the Sixth Avenue line, one at 34th Street station and one at Fourth Street station. Some important details concerning these and the interlocking machines installed throughout the entire Independent Division are given in the accompanying tabulation.

Interlockings Installed on Independent Subway

	Size of Frame	Working Levers	No. of Switches	No. of Interlocking Signals	No. of Automatic Train Stops
6th Avenue line—					
34th St.	68	55	20	42	45
W. 4th St.	56	35	12	34	35
49 machines previously installed on Independent lines	1,861	1,471	657	1,326	994
51 machines on all Independent lines	1,985	1,561	689	1,402	1,074

Power for signaling is obtained from two points on the low-voltage a-c Consolidated Edison network system at each passenger station. Insulating transformers of approximately one-to-one ratio, one on each source of power, with an automatic changeover switch provide normal and reserve power at all times to the signal-power mains.

The signal-power mains are run in ducts or on messenger cable throughout the system. In order to sectionalize these mains in case of power interruption, and to reduce the effects of electrostatic capacitance, the mains are installed in sections of less than one mile in length. Each section of mains is a complete unit in itself.

Potential relays assure changing over of power to reserve supply if normal supply is interrupted or before a dangerous low voltage is reached. Manual reset back from reserve to normal power is provided to avoid any floating of contacts between normal and reserve control should voltages fluctuate. One very important requirement of these change-over switches is that they must operate and the signal main power must be restored in a maximum of three cycles, or 0.05 second, in order that no interruption to the signal circuits shall occur while transferring energy from the normal source to reserve source or vice versa. Any open circuit or low voltage on either of the normal or reserve power supplies is indicated by a light at each source and by a light and alarm bell in the nearest signal tower for a series of sources.

Protection is provided against grounds and electrostatic capacitance by a low-resistance connection from the negative main to ground through a low-resistance winding of a double-element relay. Normal electrostatic capacitance current from the positive main to ground completes the circuit and normally energizes this low-resistance winding of the double-element relay. The high-resistance winding is energized locally from the mains in series with a fixed capacitor. Any control wire that becomes grounded has its relay or other control apparatus protected from electrostatic potential. Any grounded positive wire or equivalent insulation weakness will disturb the phase relationship of the two windings of the double-element relay, open its front contacts, and close an added low-resistance path to ground over back contacts, shunting the relay, holding it down, and giving additional protection while the ground remains. Grounds are indicated by light

Interlocking signal board at the West Fourth Street station; indicator board at top shows locations of all trains in entire section covered by this board

indicators locally, and by light indicators and an alarm bell in the nearest interlocking control tower. The relay must be manually reset when the ground is removed.

Typical grade-time and station-time signal control circuits have been described previously.[12] Grade-time controls may be one- or two-block clearing as may be necessary, although two-block clearing is most ideal and is used wherever possible and practical.

The all-electric track switch-operating and dynamic-indication circuit is used with a magnetic brake to hold the track switch in the last operated position should energy be removed for any reason. In addition, a polarized switch repeater circuit indicates that switch movement, switch points, and switch operating lever are all in unison before signals can be given for a route over the switch.

ILLUMINATION

Stations of the Sixth Avenue subway are illuminated at an intensity of about two foot-candles throughout, except on stairways and platform edges, where the intensity is higher. Illumination is furnished throughout both stations and tunnels by 120-volt incandescent lamps connected in groups of five in series for operation on 600 volts. Energy for lighting is obtained from the 120-volt a-c network of the Consolidated Edison Company, a step-up transformer being required at each point of supply to furnish energy at 600 volts. The use of 600-volt lighting circuits permits use of the third rail as an emergency source of supply at comparatively low cost. Furthermore, this arrangement was less expensive to install than multiple lighting, even including the step-up transformers.

Power for lighting normally is supplied through two transformer rooms located at either side of each station. These transformers are supplied from separate direct feeders from the low-voltage network. About half of the station platforms, stairways, and passageways is lighted from each transformer, so that in case of failure of either source about half normal illumination will remain throughout the station. Should both sources fail, the lighting circuits may be connected directly to the third rail circuit by means of transfer switches in the transformer rooms.

Between stations, each track of the subway is illuminated by two lines of lamps, one on each side; the lamps in the two lines are "staggered" and spaced approximately 80 feet apart. One line is supplied from the adjacent station in one direction, and the other line from the adjacent station in the other direction. In case of failure of power on either circuit, an automatic transfer switch will connect the circuit to the other transformer of the same station. This switch automatically returns to normal position upon restoration of power. Like the station lighting, the tunnel lighting may be connected to the third rail in case of emergency, by means of a transfer switch.

MISCELLANEOUS ELECTRICAL APPLICATIONS

Among other electrical or electrically driven equipment used in the subway are: ventilating fans, moving stairways, drainage pumps, and entrance turnstiles. Normally, the movement of trains through the tunnels provides a sufficient circulation of air. When train operation is interrupted, however, and particularly when there is smoke, forced ventilation becomes necessary in the deep tunnels. For this purpose, fan chambers have been provided to house exhaust blowers of sufficient capacity to change the air in the adjacent sections of the subway approximately every 15 minutes. These blowers are of various capacities, ranging up to 140,000 cubic feet per minute, under pressure of approximately two inches of water. The entire emergency ventilation system is remote controlled from the power dispatcher's office on 53d Street. In addition, the fans in any particular section of the subway will be started whenever the emergency alarm in that section of the subway is operated.

Pump chambers are located at all low points in the subway with sumps of capacities of about 7,000 gallons each. Standard equipment for these pump chambers consists of three pumps, one having a capacity of 1,000 gallons per minute, and two with a capacity of 200 gallons per minute. Each pump is driven by an induction motor, and is automatically controlled by means of float switches.

Telephone service for the Sixth Avenue subway, as for the rest of the Independent Division, is furnished from a private branch exchange connected to the New York Telephone Company system. A telephone switchboard and associated equipment is situated in the building on 53d Street which also houses the power-control equipment for the entire system. Telephones are located in all change booths, substations, rectifier chambers, signal towers, dispatchers' offices, circuit-breaker houses, pump rooms, and other enclosures where necessary, and also throughout the length of the subway at intervals of about 600 feet. At each of the latter locations, there also is an emergency alarm pull box, the purpose of which is to cut off power from the third rail in the immediate area. The locations of these telephones and alarm boxes are indicated by blue lights.

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Standard Basic Impulse Insulation Levels

This report of the joint committee* on co-ordination of insulation of AIEE, Edison Electric Institute, and National Electrical Manufacturers Association is the culmination of more than ten years' study to establish basic insulation co-ordination. It specifies basic impulse insulation levels in terms of a withstand voltage for a specified test wave. These values are to be the bases for various AIEE and other standards now in course of development or revision.

CULMINATING over ten years' work on insulation co-ordination during which the fundamentals of making impulse tests were investigated and standardized, as well as basic levels set up and provisionally tried out, the joint AIEE-EEI-NEMA committee on insulation co-ordination at its meeting held in November, 1940, agreed unanimously to adopt as standard the series of basic impulse insulation levels given in table I. These are the same values given in the paper presented at the AIEE winter convention, January 22–26, 1940, "Basic Impulse Insulation Levels" by Sporn and Powel (*AIEE Trans., Oct. '40 Sec., p. 596–8*). The purpose of this present report is to call attention to the fact that these basic levels have now been adopted and to the general conditions under which they apply.

The general principle of insulation co-ordination requires a reasonable margin between the voltage level held by the protective device (the protectable level) and the various basic levels themselves to insure that adequate protection is provided. The values in table I have been set up on this basis. It is felt that the values so set up are on a sound basis and that they are most likely to stand without change for a long time. It is the opinion of the committee, therefore, that the various technical committees working on standards can adopt the values given in this report for standardization purposes, and it is further believed that the use of these values will result in ultimate over-all benefit to the industry.

When first formed, the joint committee adopted as a statement of principles the following:

"The co-ordination of insulation involves three steps:

1. Establishment of insulation levels.

2. Specification of insulation strengths of all classes of equipment in established impulse levels.

3. Allocation of the insulation levels to the nominal system voltages, taking into account all operating and environmental conditions."

The adoption of the standard insulation levels in table I of this report completes the first step of the committee work.

DEFINITION OF BASIC IMPULSE INSULATION LEVELS

To clarify the meaning and intent of the levels which are given in table I, it may be well to mention here two fundamental definitions. It is believed that these definitions and the associated comments clearly indicate the requirements of any apparatus which is built to these levels and is reported as conforming to them.

"BASIC IMPULSE INSULATION LEVELS

"Basic impulse insulation levels are reference levels expressed in impulse crest voltage with a standard wave not longer than 1.5×40 microsecond wave. Apparatus insulation, as demonstrated by suitable tests, shall be equal to or greater than the basic insulation level."

This requires that apparatus conforming to these levels shall have a withstand value not less than the kilovolt value given in the second column of table I. It is also understood that apparatus conforming to these requirements shall be capable of withstanding the specified voltage whether the impulse is positive or negative in polarity.

"WITHSTAND VOLTAGE (FOR AN IMPULSE)

"The withstand voltage of a test specimen under an impulse of any given wave shape, polarity, and amplitude, which does not cause disruptive discharge on the test specimen, is the crest value attained by that impulse."

EXCEPTIONS TO TABLE I

Taking cognizance of the fact that some apparatus insulators do not at the present time fully meet the levels given in table I, the committee recognized certain exceptions. These exceptions apply to insulation levels 150, 200, and 250 kv but only for switch and bus insulators and apparatus employing these insulators, with the understanding that after January 1, 1943, all equipment will meet the values given in table I. Any new or modified designs of such apparatus completed prior to that date should, of course, conform to the values given in the table. This exception further definitely states that it will exist as an exception only until January 1, 1943, after which no equipment will be excepted from meeting the requirements of table I if such equipment is represented as meeting "Standard Basic Impulse Insulation Levels."

Table I. Standard Basic Impulse Insulation Levels

Reference Class (Kv)	Basic Impulse Level (Kv)
1.2	30
2.5	45
5.0	60
8.7	75
...	95
15	110
23	150*
34.5	200*
46	250*
69	350
92	450
115	550
138	650
161	750
196	900
230	1,050
287	1,300
345	1,550

* For switch and bus insulators, and apparatus such as air switches and power fuses employing these insulators, the levels of 150, 200, and 250 kv shall become effective on January 1, 1943, with the understanding that any redesign or modification of such equipment completed earlier than January 1, 1943, shall be made on the basis of 150, 200, and 250 kv levels. In the interim and for existing designs of this equipment, values of 145, 190, and 240 kv will be recognized as exceptions for these three classes, respectively.

NOTE: Attention is called to the fact that equipment carrying a power-frequency voltage rating which is numerically the same as the "Reference Class" in table I is not necessarily required to have the corresponding impulse level given in the table. Decisions in this regard are provided for in the two remaining steps mentioned above in the committee's original statement of principles.

* Chairman of AIEE group is Stanley Stokes (A'16, F'29) consulting electrical engineer, Union Electric Company, St. Louis, Mo.; of EEI group, Philip Sporn (A'20, F'30) vice-president in charge of engineering, American Gas and Electric Service Corporation, New York, N. Y.; of NEMA group, C. A. Powel (M'20) manager, industry engineering department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Report presented informally at the AIEE winter convention, Philadelphia, Pa., January 27–31, 1941.

Automatic Control of Aircraft

C. D. BARBULESCO
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A method of controlling aircraft through electromagnetic radiations is described here in which the controls are preset and the aircraft is flown and landed on a predetermined course in any kind of weather conditions. The operation is entirely automatic and the presence of a control operator is not needed. The solution of this problem was made possible by the development of two novel aids for fog navigation and fog landing, namely, the aircraft radio compass and the ultrahigh-frequency marker beacon.

THE problem of remote control of aircraft was initiated at the end of World War I. Due to lack of stability of the airplanes and the primitive status of aircraft radio at that time, the first attempts were not very successful. In the last few years, however, the great advance in both aviation and aircraft radio made the solution of this seemingly difficult problem quite simple.

Two methods have been successfully developed. In the first method the control operator sends into space a definite number of electromagnetic impulses using an ordinary telephone dial. It is obvious that if the operator is on the ground the radius of action of such a device is quite limited, because the airplane must remain in full sight of the operator all the time. In order to increase the range of this aerial torpedo, it is necessary for the control operator to follow it in another airplane.

It is possible, however, to navigate a pilotless airplane over a predetermined course of considerable span, and to land it safely at the end of its journey. This operation can be rendered entirely automatic; it can be performed in any weather conditions and without the presence of a control operator.

Six devices of novel design have brought about the success of such an enterprise. The first is the automatic pilot, which maintains the airplance in proper flying attitude. The second device is the aircraft radio compass, which is capable of controlling the rudder of the airplane through the automatic pilot, and thus can direct the aircraft toward a desired guiding radio station on the ground. The third device is the ultrahigh-frequency marker beacon, which is associated with the radio guiding station. As soon as the airplane arrives over the guiding station this device acts as an invisible finger which reaches through the space and automatically dispatches the airplane toward the next predetermined guiding radio station. In this manner the airplane can be flown automatically over a row of control stations arranged in a straight line or in any desired course.

The fourth type of equipment developed is an altitude control mechanism, and the fifth is a power control device. Finally it was necessary to develop an interlocking electromechanical system in order to co-ordinate and synchronize the automatic landing operation.

A paper presented: (1) at the AIEE Middle Eastern District meeting, Cincinnati, Ohio, October 9–11, 1940; and (2) at the conference on air transportation, AIEE winter convention, Philadelphia, Pa., January 27–31, 1941.

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A more detailed description of the theory and operation of these devices is necessary before analyzing the technique of the automatic landing of aircraft.

ATTITUDE CONTROL

The Artificial Horizon. The airplane is a free body in space having six degrees of freedom, three translational and three rotational. In figure 1, an airplane is represented with reference to three axes in space. The translations occur along the X axis (forward motion); along the Y axis (sidewise motion); and along the Z axis (up or down motion). The rotational or angular degrees of freedom are: rotation about the X axis (bank), controlled by the ailerons; rotation about the Y axis (pitch), controlled by the elevators; and rotation about the Z axis (turn), controlled by the rudder.

For each degree of freedom there are instruments and radio devices informing the pilot of not only the amount of motion, but of the rate of motion as well. The development of these instruments and radio devices made the problem of blind navigation and blind landing much easier than anticipated.

Using only a radio compass for direction, two marker beacons for position, and a sensitive barometric altimeter corrected by radio for altitude, Major A. E. Hegenberger executed on May 9, 1932, the first complete solo blind takeoff and landing at Patterson Field, Ohio. This experiment was not a stunt, because it was followed by thousands of blind landings executed by hundreds of other Army Air Corps pilots at various fields using the same type of equipment.

The attitude of the airplane in these landings was maintained with the artificial horizon, and the turns were

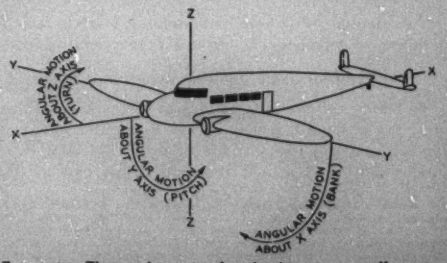

Figure 1. The airplane as a free body in space, illustrating its translational and rotational degrees of freedom

executed using the directional gyro. These gyroscopic instruments are vital in fog flying and landing.

The purpose of the artificial horizon is to provide a fixed reference for maintaining flight control in fog. In clear weather the pilot uses the natural horizon *as reference.* In fog the artificial horizon provides a substitute for the natural horizon. A small airplane is painted in silhouette on a dial in front of a pointer bar, which is connected to a gyroscope spinning about a vertical axis. As the airplane banks, climbs, or dives, the silhouette does likewise, but the pointer bar, being actuated by the gyro, remains horizontal. Under foggy conditions it is only necessary for the pilot to keep the silhouette in line with the bar and parallel to it in order to maintain flight attitude.

The Directional Gyro. A magnetic compass is worthless in fog on account of violent and amplified oscillations, produced as soon as the pilot attempts any kind of turn. These oscillations will not disappear until after the airplane has resumed a straight course. The directional gyro allows the pilot to keep a straight course and thus to stabilize the magnetic compass after executing a turn in fog.

On this instrument the sensitive element is a concentric card divided into 360 degrees. The pilot observes the card in relation to a lubber line and thus obtains an accurate index of turn. The card is maintained in fixed position in space by a gyro spinning about a horizontal axis. With the help of this instrument, 180-degree turns can be executed in fog with the greatest of ease.

The Automatic Pilot. In automatic flight the gyroscopic elements of the artificial horizon and the directional gyro actuate the controls of the airplane and keep it in level flight and on its course. The relative movement between the gyros and their casing is converted by means of air pick-offs and air relay systems, into movements of a hydraulic servo unit which in turn provides power for moving the controls. The horizontal gyro controls the ailerons and elevators while the directional gyro controls the operation of the rudder.

AZIMUTH CONTROL

The Aircraft Radio Compass. With the aid of the radio compass the pilot can fly toward a known radio station on the ground. This device comprises a vertical nondirectional antenna, a receiving loop mounted perpendicular to the longitudinal axis of the airplane, a balanced modulator, a conventional aircraft radio receiver, and a right-and-left indicator.

By simply maintaining the needle in zero position the pilot can head the airplane toward a control station or away from it. In order to eliminate the 180-degree ambiguity, the radio compass is disposed so that, when flying toward the station, if the pilot steers to the right the needle deflects to the left. When flying away from the station, if the pilot steers to the right the needle also deflects to the right. In both cases the needle deflects toward the station side and shows the pilot in what direction to turn in order to head the airplane toward the control station.

This versatile radio device was developed in Germany by Doctor Dieckman in 1926, and perfected in the United States by Air Corps engineers. It is of great value for fog navigation and fog landing, thus increasing the efficiency and safety of the airplane.

Figure 2 shows a simplified circuit of a modern aircraft radio compass. As long as the airplane flies toward the radio station the plane of the loop is parallel to the magnetic lines of force of the radiated field and there is no electromotive force induced in the loop. The needle of the indicator remains at zero until the airplane is steered to the right or to the left. It is obvious that the electromotive forces induced in the loop, when its normal takes two symmetrical positions with the course, are 180 degrees out of phase.

The balanced modulator compares these phases in the two coils of the electrodynamometric type of indicator. As may be readily seen from the simplified diagram, the fixed coil is fed directly with the low-frequency current generated by the modulator, while the moving coil receives the rectified component which modulates the incoming carrier.

The Air Corps experts have succeeded in developing means of causing the right and left movements of the radio compass indicator to correct the directional gyro in the automatic pilot in order to maintain the true heading of the airplane toward a radio transmitting station. By means of this connecting link, the pilot can fly to his destination merely by tuning the radio compass to a radio station located in the vicinity of his landing field.

An elegant solution of this difficult problem was offered by Major Carl Crane of the Air Corps in 1935. The principle of operation may be readily understood from figure 3. The direction of rotation of a minute reversible air turbine is controlled by an air vane carried by the movement of the radio compass indicator. The shaft of the turbine operates through a system of gears, a single-pole double-throw switch, reversing the current in the field windings of a differential d-c series motor. This servo motor in turn controls the air pick-off device of the directional gyro of the automatic pilot. Thus the rudder

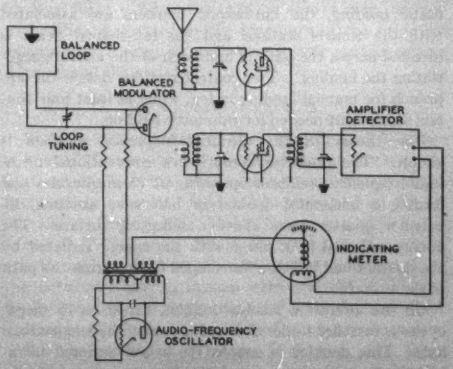

Figure 2. Simplified diagram of the radio compass

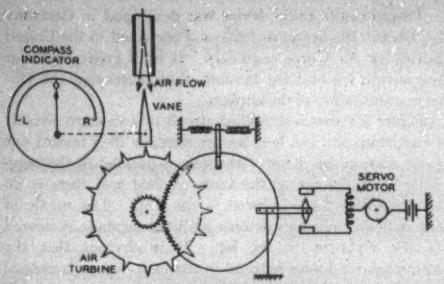

Figure 3. The directional relay controlling the rudder from the output of the radio compass

is automatically operated until the needle of the indicator returns to zero position and through the air vane stops the air turbine. At this moment the airplane is headed toward the control station.

The Ultrahigh-Frequency Markers. The pilot can determine well enough when he arrives over the control radio station from the reversal of the indications in the radio compass. A better and more positive indication is provided by the ultrahigh-frequency marker. In contrast with the radiation pattern of the radio control station which is omnidirectional, the radiation pattern of the ultrahigh-frequency marker is highly directional.

There are two types of ultrahigh-frequency markers, the fan and the "Z" type. Both operate on 75 megacycles and radiate into space either a fan-shaped electromagnetic beam or an inverse cone of electromagnetic energy. The fan-shaped beams are used mainly across the radio range courses as distance indicators, or parallel to the boundary of the landing field for fog landing purposes. The "Z" markers are used in conjunction with the radio range stations to fill the cone of silence and give a positive indication to the pilot when he arrives over the station. This indication is in general a flash of light on the instrument board.

In the Air Corps systems of blind landing and automatic landing, the fan-shaped markers are associated with the control stations and the fan-shaped beam is directed across the path of approach of the aircraft negotiating the landing. Two control stations define the approach for manual landing in fog, while at least four control stations are needed for automatic landing.

The theory of the ultrahigh-frequency markers is simple. The projector comprises a conventional ultrahigh-frequency oscillator operating at 75 megacycles and feeding a horizontal doublet or half-wave antenna, located a quarter wave above a reflecting surface. The energy reflected is in phase with the energy radiated by the doublet and builds a fan-shaped beam across the path of the aircraft.

On the aircraft a similar doublet, tuned to 75 megacycles is installed under the fuselage along the longitudinal axis. This doublet is coupled to a conventional ultrahigh-frequency receiver, which operates a relay. In figure 4 the shape of the beam is indicated in a horizontal and vertical plane. The combined effect of the transmitting and receiving directional doublets produce a much sharper virtual beam indicated in dotted lines. The relay remains closed and the indicating light flashes only during the time the airplane passes through the virtual beam.

The Control Stations. Each control station comprises a conventional medium-frequency transmitter feeding a nondirectional vertical mast antenna, and an ultrahigh-frequency marker-beacon projector. The doublet antenna of the marker projector is oriented parallel to the direction of flight and throws a curtain of electromagnetic energy across the path of the airplane.

The range of frequencies of the medium-frequency transmitter is 200 to 400 kilocycles. This band is actually used for aerial navigation purposes. The frequency of the marker beacon has been standardized at 75 megacycles by the Army, the Navy, and the Civil Aeronautics Administration.

In figure 5 the disposition of the control stations for automatic landing is shown. Obviously they are aligned in the direction of flight, the landing being negotiated against the wind. The furthermost station, number 1, is approximately 15 miles from the landing field. Station number 5, located across the field, controls the heading of the airplane during the last phase of the landing operation. Each nondirectional transmitter has a different frequency while all the ultrahigh-frequency marker transmitters operate at 75 megacycles.

The Automatic Dispatcher. This device constitutes the brains of the automatic flight and landing operation. It comprises a marker-beacon receptor, a selector switch, and an automatic tuning device, operating the radio compass. In figure 6 a simplified diagram shows clearly the principle of operation.

The energy received by the marker-beacon receptor from the marker-beacon projector, actuates a relay, which advances the selector switch one step. The arm of the selector closes the corresponding contact and sends current into the armature and one of the field windings of a differential series motor, actuating the tuning of the radio compass. The angular position of the selective cams in the automatic tuner is so adjusted on the shaft that the current is automatically cut off in the motor when the radio compass is tuned to the radio control sta-

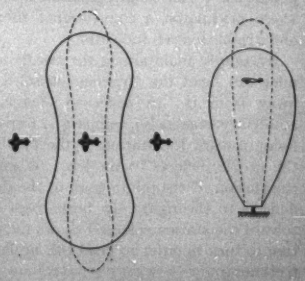

Figure 4. The actual and the virtual (dotted) beam of an ultrahigh - frequency marker beacon in horizontal and vertical planes

tion toward which the airplane is headed. This is done by insulated fingers riding on the edges of the cams controlling the position of the arms of the single-pole double-throw spring switches.

On the tuning shaft there are as many selective cams as control stations on the ground. Each is adjusted for the automatic tuning of the compass to the corresponding control station when the sweeping arm of the selector switch closes the corresponding contact.

As described hereinbefore, the output of the radio compass actuates the rudder of the airplane through the automatic pilot, and the airplane is flown toward and over any control station. When arriving there, the energy received from the marker beacon advances the selector switch one step further, and immediately the radio compass is tuned to the next control station. In this manner the airplane may be promptly dispatched from point to point over a row of stations defining any desired course.

The Automatic-Landing Technique. The automatic landing is negotiated as follows: Assume that the airplane is flown at an altitude of 1,000 feet within the range of station 1. The radio compass is tuned to this station and the airplane is automatically flown toward it. Arriving over station 1, the airplane enters the field of the marker-beacon projector associated with it. The selector switch advances one step and tunes the radio compass to the frequency of station 2. Now the airplane flies automatically toward this station, gradually directing its flight into the wind following the alignment of the stations.

Arriving over control station 2, the selector switch advances one step further and the compass is tuned to station 3. When over station 3, the contact not only causes the tuning of the compass to station 4 but also closes another circuit actuating the throttle control. This control is identical with the automatic tuner of the radio compass, using a cam preset for a position of the throttle corresponding to a glide of about 400 feet per minute.

Over station 3 the airplane therefore starts to glide into the field, and if there is no wind, arrives over station 4 at an altitude of about 200 feet. Passing over station 4, the compass is again switched to the frequency corresponding to station 5, located on the other side of the field,

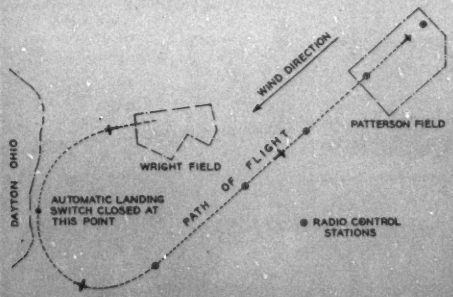

Figure 5. Practical arrangement of radio control stations for automatic landing

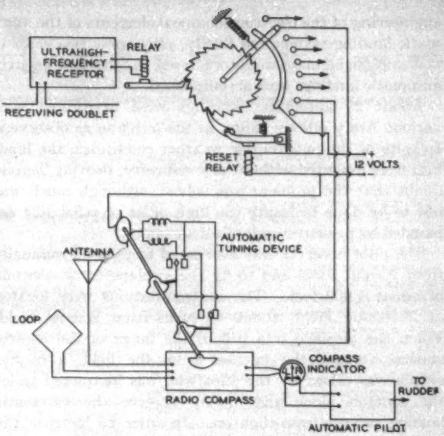

Figure 6. The automatic dispatcher

and the airplane maintains the proper heading into the wind until the wheels touch the ground. The impact produces a displacement of the component parts of the landing gear closing a switch which closes the throttle. After rolling over the ground for a little while, the tail drops, and the airplane automatically comes to a complete stop.

ALTITUDE CONTROL

In conditions of strong wind the glide is much steeper and the airplane might land before crossing the boundary of the field. In order to prevent this a small mirror is glued to the hand of the barometric altimeter. When the hand reaches a position corresponding to a minimum safe altitude of 200 feet, the mirror picks up a beam of light which is reflected upon a photoelectric cell. The output of the cell actuates a relay closing the circuit which operates the throttle, setting it in forward position for level flight. When the airplane arrives over the control station 4, located at the boundary of the field, the selector switch again actuates the throttle control setting it for normal glide.

EXPERIMENTAL RESULTS

Early in 1935 Lieutenant (now Major) Carl J. Crane of the Air Corps planned the development work at the Materiel Division that led to the accomplishment of the first entirely automatic landing of an airplane on August 23, 1937. During 1935 Major Crane was assisted by Major G. V. Holloman, Mr. R. K. Stout and the author, and through their joint effort the various components of the automatic landing system were designed, built, and finally installed in a single-engined Fokker airplane which was used exclusively for the initial flight research, most of which was conducted by Major Holloman. Mr. Stout and the author were charged with most of the design and

engineering of the electromechanical elements of the automatic landing system and finally, after some two years of constant flight and laboratory research, the first entirely automatic landings were accomplished.

About 25 automatic landings were negotiated with various Army officers riding in the airplane as observers. In spite of the unfavorable weather conditions, the landings were executed without any difficulty, proving beyond doubt that the problem was solved, although much was left to be done to insure the high order of reliability demanded by present standards of air safety.

The pilot observer was instructed to take off manually from Wright Field and to fly the airplane at an altitude of about 1,000 feet. The control stations were located at Patterson Field, about six miles from Wright Field. When the airplane was still in the range of the control station situated the farthest from the field, a master switch was closed by the pilot who was instructed to let the controls alone and merely observe the automatic landing process from then on. In order to increase the confidence of the observer in the automatic controls, a parallel row of contacts, associated with the selector switch, flashed lights revealing the identity of the control station toward which the airplane was flying at any particular moment.

POSSIBLE APPLICATIONS

One of the first possible applications of this development is to relieve the modern pilot of many routine physical duties. When a pilot can see the ground, the amount of information he receives through his senses is amazing. When flying in conditions of poor visibility he must gather and integrate this information from scores of instruments displayed before him. The time element, however, is not very important in fog flying, and considerable tolerances are allowable in many of the pilot's tasks.

In the process of landing in fog, however, both time and space are at a premium. The pilot actually needs his information with greater accuracy and he must integrate and interpret it very rapidly, in order to act without risk of confusion. The automatic device described relieves the pilot of the continual strain of maintaining the airplane in flight. His responsibilities become broader, watching the condition of the ship and engines, obtaining weather information through radio, and keeping in contact with the traffic dispatchers.

The possible military applications of this development are left to the imagination of the reader. With nominal additional development it will be possible, in the near future, to cause an airplane to take off, to continue in automatic flight on a predetermined course, and then to land automatically at a predetermined place, entirely without human control.

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2. The Flightray, Preston R. Bassett and Joseph Lyman. *The Sperryscope*, volume 9, July 1940.

3. Aircraft Radio and Electrical Equipment (book), Howard K. Morgan. Pitman, 1940. Chapter IX shows complete diagrams of modern aircraft radio compass.

Mobile Substation for Emergency Power Supply

FOR quickly supplying or restoring power in a serious emergency, this completely factory-built 1,000-kva mobile substation has been built for the Central New York Power Corporation at Syracuse, N. Y., by the General Electric Company. The unit is mounted on a special chassis and can be hauled at speeds up to 40 miles per hour. Over-all dimensions, including extensions, are 11 feet 6 inches high, 21 feet long, and 8 feet wide; the height can be reduced to 9 feet 10 inches for low clearances. Total weight, including chassis, is almost 10 tons. Use of a forced oil cooling system permitted the substation to be built in compact weight and size.

The substation consists of one three-phase 1,000-kva transformer, with primary and secondary switching equipment and lightning arresters. It is designed to take power from high-voltage lines of 11, 13.2, 22, 33, or 44 kv, transform it, and supply it to systems of 230, 460, 2,300, 4,000, or 4,600 volts. Installation is merely a matter of parking and grounding the unit; attaching incoming high-voltage lines to one side; and the secondary system lines supplying the customers to the other side. In addition to emergency service, the mobile substation also will be used to by-pass regular substations while repairs are being made or while maintenance work is being done, thus preventing interruption of service.

Institute Activities

Draft and Overdraft

A Message From President Sorensen

AMERICA'S program of National Defense is the prevailing topic of conversation and discussion encountered by your president in his travels about the country in the discharge of his duties of office. Last fall the question most commonly encountered was: "What is being done in other parts of the United States for National Defense?" Currently the prevailing question is: "What are we going to do to get enough engineers to assure maintaining the production required in the Defense program?"

We are now enormously overdrawing our available supply of engineers. Not only are all available experienced engineers now employed, but this spring's graduating engineering students are practically all engaged for positions in industry or for Army or Navy engineering work immediately upon graduation. In fact, if every one of the 150-odd engineering colleges had senior classes triple the size of those that will graduate this spring, the present demand indicates that a shortage of qualified engineers and designers still would exist for the work the nation now has before it.

Engineers are not kept in storage for use in emergencies like those now current. The Defense program now in progress indicates that the 1942 demand for engineers will be as great as if not greater than the one now facing us. A continuing supply of high-quality men for engineering work must be available without interruption both for civil and military Defense operations. These engineers and other technical experts cannot be produced quickly—by legislation or mere wishful thinking—but become qualified for the rigorous requirements of their work only through a long period of educational preparation followed by years of practical experience. The more precise the work required, the more specific and thorough must be the training of the engineer to do that work.

What are we going to do to assure this necessary and continuing supply of engineers?

First and most important, not knowing for how long the acutely vital Defense program must continue, we must be prepared to augment our present supply of engineers through the medium of a program of education and training of qualified young men that will assure a supply to meet the demand. Not only must current new demands be met, but account also must be taken of the vacancies caused by superannuation, retirement, and death of the older members of the profession.

Next, because of the present great preponderance of demand over supply, it is our first duty to assure that men qualified to do engineering work are not assigned to or permitted to assume Defense duties that can be performed by persons not qualified by education and training to do engineering work. It is the duty of every engineer to aid his local Draft Board in honestly analyzing the relative need for engineers in every type of service, in classifying every drafted man according to his technical training and ability, and in placing the men where they will be most effective in the over-all National Defense program. In some instances such a basis for selection would mean retention in civilian engineering service; in all instances it could avoid waste or misapplication of the limited supply of available technically trained and experienced man power by avoiding the assignment of engineers to duties that do not require engineering knowledge. This would be of great value in the present situation.

As to the future, present indications are such as to give prominence and great importance to the question of what to plan for men now in their junior years at engineering colleges. Many of these young men are anxious to undertake their period of military service immediately. Others are being sorely tempted to drop—or at least to interrupt—their college training to answer industry's call for man power. Either of these moves would meet the present situation at the expense of later and probably at least equally vital needs for technically trained men. Pending the development of further data on these important matters, we well may consider the advisability of having engineering students now in good standing in engineering colleges continue their studies; at least until we can be more certain that the present overdraft of engineers for the production of needed defense equipment will not result in a future lack of men with minimum preparation for good engineering in industry. (That minimum preparation is deemed to be graduation from an approved course of study at an engineering college.) Such a deferment of military service already has been made for those engineering students who will complete their planned college courses by July 1, 1941. It seems logical to consider the need for extending such deferment to include students now in good standing in engineering schools who can complete their planned educational program by July 1, 1942, and who otherwise might be selected by a local Draft Board for military service prior to that date. The engineering colleges now are considering a program for accelerating the education of student engineers by omitting summer vacation periods, and by such other procedures as may be developed.

AIEE SECTIONS MIGHT HELP

Our present Draft law leaves in the hands of local Draft Boards all decisions on points such as those we have discussed in the foregoing. Although these local boards have full control of the selection of men for military service, or for their deferment, these boards cannot with maximum efficiency make many of the decisions concerning the disposition of engineers unless engineers are willing to help the boards determine with fine discretion how, and when, and where engineers of draft age best and most effectively may serve both the present and the probable future needs of National Defense. Therefore, it would seem reasonable to suggest that each Institute Section might greatly

Inspecting the Edison dynamo that was installed on the S.S. Columbia in 1880 (see page 105) and is now at the Edison Institute Museum, Dearborn, Mich., are left to right, J. W. Bishop of the Museum staff, National Secretary H. H. Henline, President R. W. Sorensen, and A. W. Meyer, Detroit Edison Company

aid the National Defense program by giving immediate and effective co-operation to local Draft Boards. With reference to practicing engineers, such co-operation could include assistance in proper classification for both military and nonmilitary Defense needs. With reference to students, such co-operation could include providing local Draft Boards in their respective localities with a record of places where engineers are needed and with something of a parallel record of student engineers being developed to fill those needs.

In any event, let's not overdraw our supply of engineers to a point below that at which we assuredly can keep our Defense program on a strong and continuing basis.

As this "message" is written your president and national secretary are in the midst of a tour embracing a large part of the United States, visiting Institute Sections and Branches, and endeavoring to meet as many as possible of the Institute's members. This is the second such tour that has been made since the current administrative year began last August.

The first tour was synchronized with the Middle Eastern District meeting at Cincinnati, Ohio, October 9–11, 1940, and included visits to 10 Sections and 7 Branches. That first tour ended November 1. This present tour of visitation will end February 17 and was scheduled to include the 1941 winter convention at Philadelphia, and visits to 14 Sections and 8 Branches. With the record-breaking registrations of 599 at the District meeting in Cincinnati, and 1,931 at the winter convention in Philadelphia, together with the membership represented by the various Sections and Branches visited, your president and national secretary have on these two tours at least exposed themselves to a total of some 5,500 persons active or interested in AIEE affairs, and have made at least something of a contact with a large proportion of these people. Indeed one of the smaller Sections reported 14 immediate new applications for membership and several more pending for attention. Also, this Section now plans to hold monthly instead of bimonthly meetings as heretofore.

Analysis of Registration at Recent Winter Conventions

District	1938	1939	1940	1941
Middle Eastern (2)	292	404	412	946
New York City and foreign (3)	767	752	743	523
North Eastern (1)	253	287	332	276
Great Lakes (5)	74	76	76	122
Southern (4)	11	16	29	27
Canada (10)	14	28	20	12
South West (7)	18	37	10	2
Pacific (8)	5	4	6	12
North West (9)	3	2	3	3
North Central (6)	2	4	2	8
Totals	1,438	1,610	1,626	1,931

Attendance at Special Features of Recent Winter Conventions

Feature	1938	1939	1940	1941
Total registration	1,438	1,610	1,626	1,931
Smoker	1,201	1,264	1,466	1,420
Dinner-dance	651	527	538	730
Inspection trips	1,012	1,167	1,700	1,055

Philadelphia Convention Sets Record; G. E. President Challenges Industry

WARNING his listeners that the American free-enterprise system—in fact the whole democratic way of life—is in imminent peril of being lost in one way or another through the present world-wide upheaval, Charles E. Wilson, president of the General Electric Company, speaking January 29, at the 1941 AIEE winter convention, urged prompt, thoughtful, and courageous action by American industry and all liberty-loving individuals. Mr. Wilson urged realistically that the mirage of the hoped-for "return of normal times" be discarded as a goal, before it has led its self-blinded followers too far, and he challengingly presented as a basis for discussion a proposed program of step-by-step action for a more probable future. The full text of this thought-provoking address appears elsewhere in this issue.

SORENSEN INTRODUCES WILSON

Presiding at the general session Wednesday morning, January 29, at which Doctor Robley D. Evans, Massachusetts Institute of Technology, was the other featured speaker, President Royal W. Sorensen introduced Mr. Wilson in these terms:

"The defense program as I understand it has its foundation in our desire to have America and such other parts of the world as may be possible continue to be places where men are free to do the things that are exemplified by the lives of many of us participating in this convention program. This morning we listened to Doctor Robley D. Evans, a physicist who, before the age of 35, received a medal for distinguished work in physical sciences. Our American freedom and equality of opportunity for all provided the ways and means for Doctor Evans without money or influence of any kind to earn his way through college and to have opportunity to gain the ability he showed us today. This evening we have on our program several others about whom we could say the same thing, but we also have with us outstanding men who, without the advantages of college courses, have by the practice of diligence in work and the building of character under our American way of life been granted the privilege of achieving great things.... These men all started work as office boys in their early teens; they all once were shipping clerks, foremen, superintendents, engineers, managers, and vice-presidents. They all are interested in the betterment of the workers in their plants, and are active members of churches. ...A chairman of the board of General Electric Contracts Corporation, a chairman of the board of the Monowatt Corporation, a chairman of the General Electric Vacuum Cleaner Company, a vice-chairman of the board of the General Electric Supply Corporation; directors of the General Electric Company, the Edison General Electric Appliance Company, the Trumbull Electric Manufacturing Company, and the International General Electric Company. These men are Charles E. Wilson, president of the General Electric Company."

ATOM SMASHING AND MEDICINE

Doctor Evans, a Nobel laureate, opened the Wednesday morning session with an illuminating address entitled "Atom Smashing and Its Application to Medicine." Doctor Evans' address is scheduled for publication in ELECTRICAL ENGINEERING as soon as a manuscript can be made available. His able treatment succeeded admirably in bringing the highly technical topic down

In addition to hotel and meeting-room lobbies, the winter convention committee took over and specially fitted the Bellevue-Stratford Hotel's "Planet Room" to serve registration purposes and as general convention headquarters. Below at right is shown the women's lounge and the operating center of the trips committee. In the general view, below at the left, the main registration desk is at the left, the novel registration bulletin board (see facing page) in the center background, and a portion of the men's lounge at the right

out of the stratosphere of human understanding.

EDISON MEDAL PRESENTATION

At a general session held Wednesday evening, with appropriate ceremony, President Sorensen presented the Institute's Edison medal to Doctor George A. Campbell, retired research engineer of the Bell Telephone Laboratories, for 1940 "in recognition of his distinction as scientist and inventor, and for his outstanding original contributions to the theory and application of electric circuits and apparatus." Chairman L. W. W. Morrow of the Edison medal committee, outlined the history and significance of the award, and Past President Doctor Frank B. Jewett sketched the career and contributions of the medalist. Doctor Jewett's address and Doctor Campbell's response may be found elsewhere in this issue; a brief biographical sketch of Doctor Campbell was given on page 30 of the recent January issue.

REGISTRATION SETS NEW RECORD

With a verified registration totaling 1,931, the 1941 AIEE winter convention set a new all-time high mark for winter convention registered attendance. The convention was held at the Bellevue-Stratford Hotel in Philadelphia, January 27–31 under the sponsorship of the Philadelphia Section. This is the first time that the winter convention has been held outside New York City since 1924, at which time it also was held in Philadelphia—with a registration of 1,738.

Continuing the trend toward broader technical programs, the convention this year included 20 technical sessions and 9 technical conferences, compared with 18 and 8, respectively, last year. The regular technical sessions accommodated the presentation and discussion of 82 technical papers; 4 scheduled conference papers and numerous informal progress reports and discussions were accommodated in the technical conferences.

ENTERTAINMENT AND INSPECTION TRIPS

The two principal social events were the traditional dinner-dance and smoker, supplemented by a women's dinner-and-bridge party which paralleled the men's smoker. The dinner-dance attendance, 730, establishes a new record, the previous highest figure having been 651 in 1938; the smoker attendance, 1,420, is a close second to the 1940 record of 1466. For the women, the local committee's generous program of trips and special affairs provided three full days of activities, Monday having been left open. For the men, a dozen regularly scheduled inspection trips were provided. Comparative attendance figures for principal convention events are given in one of the accompanying tabulations.

Related novel and effective features of winter-convention registration were a teletypewriter installation operated from the registration desk which gave a visible display of each name as it was transcribed at a receiving stand onto a standard tape, and the 8-by-12 foot display board shown above, onto which each name was stripped immediately

Among the special gatherings of different groups during convention week were an informal dinner meeting of Rutgers alumni, an informal dinner meeting of Columbia University electrical engineering alumni, and the annual dinner of Eta Kappa Nu celebrating the society's annual recognition of outstanding young electrical engineers (*EE, Jan. '41, p. 42 and 52*). Reports of other convention-week events appear on the following pages.

Some High Lights of Convention Conferences and Committee Meetings

AN increased number of technical conferences and meetings of most of the Institute's standing committees contributed to the interest of the 1941 winter convention at Philadelphia, Pa., January 27–31. The nine technical conferences were on the following subjects: air transportation, communication networks, electronic inverters, fluorescent lighting, new electrical aids in biological and medical research, nonlinearity in electrical machine problems, power distribution in industrial plants, Canadian and United States standards, and use of electricity in processing metals.

In addition to the regular meetings of the board of directors and the national nominating committee, both reported elsewhere in this issue, the following Institute committees met during convention week: air transportation, automatic stations, basic sciences, communication, domestic and commercial applications, education, electrical machinery, electrochemistry and electrometallurgy, instruments and measurements, Lamme Medal, land transportation, legislation affecting the engineering profession, lightning arrester subcommittee of the protective devices committee, membership, networks subcommittee, planning and co-ordination, power generation, protective devices, research, safety, Sections, standards, standards co-ordinating committees 4 and 6, technical program, transformer subcommittee. The usual luncheon for Student Branch counselors was held Thursday, January 30, and the District prize paper chairman met Tuesday, January 28.

Such high lights of general interest as were reported from these meetings by the chairmen follow.

CONFERENCE ON AIR TRANSPORTATION

The conference on air transportation, held January 29, was opened with the presentation of the papers on "Application of Electric Power in Aircraft", by T. B. Holliday, U. S. Army Air Corps; "Automatic Control of Aircraft", by C. D. Barbulesco, Antioch College; and "An Electrical Engine Indicator for Measuring Static and Dynamic Pressures", by E. J. Martin, C. G. Grinstead, and R. N. Frawley, General Motors Corporation. Following the presentation of these papers, a

Analysis of Attendance at 1941 Winter Convention

Classification	Philadelphia	Districts 2*	1	3	4	5	6	7	8	9	10	Foreign	Totals
Members	307	297	218	396	10	100	4		9	2	11	1	1364
Men guests	110	80	36	85	4	15	1		1		1	1	334
Women guests	113	39	22	40	4	8	3	2	2	1			233
Totals	530	416	276	531	27	123	8	2	12	3	12	2	1931

* Outside of Philadelphia Section territory.

general discussion was held on d-c versus a-c electric power supply systems for aircraft. The discussion led to the following conclusions:

1. A-c electrical systems for aircraft will probably not be specified for several years, or until a suitable means for maintaining constant speed at the input shaft of the main-engine-driven alternator despite variations in the speed of the main engine has been developed.

2. The use of auxiliary power plants for other than "stand-by" purposes in flight, or to supply electrical energy when the airplane is not in flight, is not practical from a minimum weight standpoint. The primary source of electric power for airplanes in flight will be from main engine driven generators on the airplane.

3. Due to intensive development, and design improvements in main-engine-driven generator design, airplanes in the future will probably be arranged with minimum battery capacity and all electric power in flight to be supplied from the main engine generators. This conclusion was based on the fact that approximately 45 pounds of generator can supply 120 amperes continuously at 28.5 volts, as compared to approximately 160 pounds of storage battery capable of supplying 120 amperes at approximately 18 volts for only 20 minutes.

4. The high operating speeds of a-c high-frequency motors will probably lead to considerable bearing lubrication and maintenance difficulty, and require a large reduction gear box in order to get output speeds suitable for most airplane applications, the weight of the reduction gear box in many cases offsetting the reduction in weight of the motor attained through high motor revolutions per minute.

It was further concluded that most large airplane electrical systems will be of the 24–28.5 volt d-c type with possible future development toward a 120 volt d-c supply system for very large airplanes with large operating electrical power requirements.

The meeting was attended by approximately 200 AIEE members from various government services, colleges, and electrical and aircraft manufacturing companies. (*E. E. Minor, chairman, air transportation committee.*)

CONFERENCE ON COMMUNICATION NETWORKS

A sixth annual informal conference on network analysis and synthesis, sponsored by the AIEE committee on communication, was held January 31. Three subjects were presented and discussed. "Operational and Moment Analysis of Transient Distortion in Networks," was presented by Roy C. Spencer, The University of Nebraska, and presentations of "The Repeater-Transformer, a Generalization of the Transformer Concept as Applied to Feedback Amplifiers," and "The Zero-Frequency Carrier or the Vector Envelope in the Solution of Unsymmetrical Sideband Problems, Such as Single-Sideband Transmission or Frequency Modulation" were made by Harold A. Wheeler, Hazeltine Service Corporation.

The attendance this year was very considerably less than at previous meetings (about 40 as compared to almost 200 last year). There may have been several reasons for this, a significant one being the fact that the convention this year was held in Philadelphia instead of New York, with the result that many who are only mildly interested in this subject were eliminated. As a result, the effectiveness of the meeting was greatly enhanced, and those present were greatly pleased by the resulting informality and consequent free interchange of ideas.

It was the opinion of a number of those present that the invitations in future years should be restricted to a more seriously interested group of this sort so that the same group feeling which was responsible for the success of this year's meeting may be maintained. It is the chairman's opinion that this objective is well worth serious consideration. (*Ernst A. Guillemin, chairman of the conference.*)

CONFERENCE ON ELECTRONIC INVERTERS

At the conference held January 28, 1941, the subject of electronic inverters was opened by Doctor S. B. Ingram, of the Bell Telephone Laboratories, who pointed out that in view of the fundamental similarity of inverters and rectifier circuits and the wide use of the latter, it is surprising that more inverter applications have not been found. In the informal discussion which followed it was brought out that there are a number of problems encountered in inverters which are not met in rectifiers or which occur in much less severe form. One of these is the problem of commutation. Another is the dependence of output and of circuit behavior in general on variations in magnitude and reactance of the load. Several practical inverter applications were briefly described and discussed. It was the consensus of the conference that the field of practical use of electronic inverters was necessarily limited, but that these devices had a definite field of usefulness where conditions of operation were suitably chosen. Tube life in both inverter and rectifier circuits was discussed and it was pointed out that tube operating conditions could be made as satisfactory in inverters as in rectifiers if attention was given to suitable circuit design. Experience from one large inverter installation in a d-c transmission system was cited to show that highly satisfactory tube life could be obtained under inverter conditions of operation.

Approximately 40 attended. Those participating in the discussion included S. B. Ingram, V. L. Holdaway, and D. E. Trucksess of the Bell Telephone Laboratories; W. C. White, M. S. Mead, and C. W. La Pierre of the General Electric Company; W. E. Pakala of the Westinghouse Electric and Manufacturing Company; Professor C. H. Willis of Princeton University; Professor B. K. Northrop of Cornell University; Professor A. A. Nims of the Newark College of Engineering; A. J. Williams of Leeds and Northrup; W. Richter, consulting engineer; and others. (*H. M. Turner, chairman of the conference.*)

TECHNICAL SESSION AND CONFERENCE ON FLUORESCENT LIGHTING

Under the sponsorship of the committee on production and application of light, a technical session and conference on fluorescent lighting were held on the afternoon of January 29. D. W. Atwater, chairman of the committee, acted as chairman of both.

Two papers were delivered at the Technical Session: "Fluorescent Lighting Fills the Gap", by A. A. Brainerd, and "Developments of the Glow Switch", by R. F. Hays.

Mr. Brainerd pointed out the importance of considering all factors involved in lighting design before selecting any of the modern light sources. He indicated that such factors as size of fixtures, concentration of light source, efficiencies, and cost must be given proper weight in any design. Hence, the promiscuous application of fluorescent lighting, because it is new and different, is a very dangerous procedure, although it has not been unknown since the introduction of the fluorescent lamp. The analysis of the advantages and disadvantages of the three principal light sources in modern illumination—the incandescent lamp, the high intensity mercury vapor lamp, and the fluorescent lamp—was very enlightening and constructive.

In the paper on glow switches, Mr. Hays explains the underlying theory of the switch and the problems in its construction that had to be solved in order to make it a practical instrument. He pointed out the effect of various gases and gas pressures on starting time and indicated the importance of selecting the proper metal for coating the two electrodes within the switch. Curves and data were given indicating its operation under various conditions of voltage and with various electrodes and gases.

At the close of the technical session, Chairman Atwater opened the conference with a short statement concerning the rapid growth of fluorescent lighting during the past year and the effect it has had upon raising illumination levels in industry. He pointed out that in 1939 a survey indicated that the average level in industry was less than 10 foot-candles. Today, many of the larger installations are well above 30 foot-candles, some going as high as 60 and 100 for special operations. While such installations, according to Mr. Atwater, cannot be considered as general practice yet, undoubtedly, the introduction of the fluorescent lamp and its many advantages is rapidly bringing about such a condition.

O. P. Cleaver gave a summary of the most important advances in fluorescent lamps and auxiliaries during the past year. He demonstrated the new 100-watt *T*-17 fluorescent lamp, pointing out that it produced about twice the lumens per foot available from the former sizes of fluorescent lamps commercially available. This lamp, however, was slightly lower in efficiency than the 40-watt lamp and had a lower rated life of 2,000 hours.

The small 6-watt 9-inch *T*-5 fluorescent lamp was also shown with its control equipment. This lamp, while having been available for some time, nevertheless, has recently been changed from the former oval bulb type to the round *T*-5 bulb, and its life has been increased to 750 hours. Many applications have been worked out for its use, such as bed lamps, table lamps (at least four bulbs per lamp), cash registers, instrument boards on airplanes, and others.

The 14-watt 15-inch fluorescent lamp, designed to operate two in series with a small tungsten lamp as ballast, was demonstrated next, and its use in home lighting and train lighting explained.

Other advances during the year were listed as: the introduction of the new soft white which improves the appearance of certain raw meats and vegetables and enhances the appearance of the human skin; the improvement of ballast equipment due to better design and improvements in manufacturing technique; the availability of radio-interference correcting equipment; and the solution of the power-factor problem by the widespread use of the two-lamp ballast.

Mr. Cleaver pointed out that consider-

able research work was being done on the fluorescent lamp of today and that the future would undoubtedly see different sizes and improved lamp performance and efficiencies.

Following Mr. Cleaver's talk, A. B. O'Day discussed the many improvements that had been made in lighting equipment for the use of fluorescent lamps. He mentioned the fine work that had been done by the RLM Standards Institute, the Fleur-O-Lier Manufacturers Association, and others, in improving the quality of fixtures. He noted that a greater percentage of the fixtures is now properly shielded either with louvers or glass in the interest of eyesight conservation. As proof he showed several slides of more satisfactory installations of today. Mr. O'Day closed his discussion with a series of slides showing suggested designs of fixtures for the new 100-watt lamp and the other current types to indicate what the trend in lighting fixtures for fluorescent lamps may be in the future.

J. A. McDermott next introduced the subject of fluorescent-coated high-voltage tubing and its place in modern lighting practice. He showed several slides of its use at the New York World's Fair for decorative purposes and indicated that to date this had been its biggest field of application. He pointed out that with proper construction and manufacture, the tubes could probably be made as efficient as the low-voltage types for the same color. He indicated, however, that there was no particular control of the manner of construction and manufacture of these tubes throughout the United States, and hence efficiencies were likely to vary considerably, depending upon the manufacturing process. Mr. McDermott, in closing, stated that it was entirely likely that with present underwriters' regulations concerning high-voltage equipment in interiors, the high-voltage fluorescent tubing would be slightly more costly for general lighting purposes than low-voltage fluorescent lamp installations.

Following the discussion on high-voltage fluorescent tubing, Preston Millar gave a brief summary of 125 fluorescent lighting installations which had been selected as reasonably satisfactory by some 50 utilities throughout the United States. The average foot-candles reported were 36 at the point of utilization and 28 foot-candles over-all. The power factor of these installations averaged above 90 per cent. The total wattage after the installation of fluorescent lighting was approximately 93 per cent of the former incandescent load. Daylight lamps predominated in the industrial installations, while daylight and white were about equally prevalent in all other types of installations.

Following the presentation of the prepared discussions, the conference was opened for discussion. The audience participated very actively and a number of subjects were brought up for consideration. Topics discussed included the importance of shielded fluorescent lamps for eye comfort; the necessity for considering measures to correct for radio interference; the possibilities of applying fluorescent lighting in the home; the characteristics that seem to appeal to the public, which in many instances have led to the purchase of fluorescent lighting at greater cost; the necessity for proper meter correction for measuring the new colors of fluorescent lighting; and further discussion of the cost of high-voltage fluorescent tubing for interior illumination. (*D. W. Atwater, chairman, committee on production and application of light.*)

NONLINEARITY IN ELECTRICAL MACHINE PROBLEMS

As a continuation of the general discussion of nonlinear analysis at the last summer convention the conference held January 28, concentrated on nonlinear problems connected with electrical machinery.

A. F. Puchstein, consulting engineer, Springfield, Ohio, presented the computation of current and torque in an a-c series—tool motor operating well over the saturation range of the magnetic characteristic. He substituted two straight lines for the saturation curve and introduced, at the boundary of the two regions, a correction to insure continuity of the power factor. This was very thoroughly discussed together with the question of whether or not a transient term should arise at that point. The discussion tended to support Mr. Puchstein's approach though it became rather evident that additional work is required to clear up this seemingly simple analytical treatment.

A very thorough presentation of the graphical analysis of the steady state and transient performance of saturated synchronous generators by Professor R. Rüdenberg of Harvard University followed. The elegance of the method and its applicability to both inductive and capacitive loads as well as the phenomenon of self-excitation so impressed the audience that it voted to request Professor Rüdenberg to prepare a formal paper for publication by the Institute.

Finally, Professor E. G. Keller of the University of Texas surveyed the rigorous analytical treatment of the pulling-into-step of synchronous motors, which, even without magnetic saturation, leads to complicated nonlinear differential equations. The first solution was obtained with the differential-analyzer at the Massachusetts Institute of Technology and Professor Keller demonstrated the direct analytical method, contending that any equation or system of equations solvable by mechanical means also can be obtained analytically. The interest in this new branch of advanced mathematics was evidenced by requests for references which Professor Keller has collected and systematically grouped over a period of years.

The attendance of about 40 prominent men from industry and universities demonstrated the value of conferences in this recently developed field of engineering research. (*Ernst Weber, chairman of the conference.*)

TECHNICAL SESSION AND CONFERENCE ON POWER DISTRIBUTION IN INDUSTRIAL PLANTS

The technical session and the technical conference on January 28 were devoted to the problem of power distribution in industrial plants.

Four papers were presented at the morning session, each dealing with a phase of this subject. C. A. Powel and H. G. Barnett of the Westinghouse Electric and Manufacturing Company discussed the merits of the network system for industrial plant distribution and urged further adoption of this system, particularly in the new defense industries. A. G. Darling, of the General Electric Company, Schenectady, N. Y., presented a "Short-Circuit Calculating Procedure for Low-Voltage A-C Systems". This paper included much useful and hitherto unpublished data of value to the engineer who is concerned with the design of low-voltage distribution systems. A paper dealing with the use of enclosed bus bar distribution systems for industrial plants, written by E. T. Carlson of the Trumbull Electric Manufacturing Company, Inc., Ludlow, Ky., was presented by Y. T. Chaney of the same company. A technical conference paper by R. C. R. Schulze of the Public Service Electric and Gas Company of Newark, N. J., on the subject of short-circuit calculations, dealt specifically with the problems encountered in designing industrial plant distribution systems.

The technical conference held in the afternoon attracted a considerable group of plant electrical engineers, utility power sales engineers, and others interested in the general subject. Several members of the industrial power applications committee were present and took part in the discussion. The general lack of reliable information and test data bearing on the performance of factory distribution systems was stressed. It was proposed that the committee should sponsor further papers on various aspects of this general subject and that, ultimately, a design manual for industrial distribution systems might be compiled and issued as a committee report or publication. (*J. J. Orr, chairman, committee on industrial power applications.*)

TECHNICAL SESSION AND CONFERENCE ON USE OF ELECTRICITY IN PROCESSING METALS

A technical session and conference on the use of electricity in processing metals were held Friday, January 31, under the joint sponsorship of the AIEE committee on electrochemistry and electrometallurgy and the American Society for Metals.

The papers presented at the technical session were "Large Electric Arc Furnaces—Performance and Power Supply" presented by B. M. Jones and C. M. Stearns of Duquesne Light Company, and "Electrolytic Process of Scale Removal From Steel" by H. W. Neblett of Inland Steel Company. Both papers were well received and actively discussed by those in attendance.

At the technical conference Doctor Paul Faragher of the Aluminum Company of America presented a paper on "Light Metal Alloys; Their Production, Fabrication, and Use". Doctor T. Holland Nelson presented a paper on "Stainless Steel and Its Production". There was a large attendance at the conference and both papers were enthusiastically received.

Committee Meeting. A meeting of the committee on electrochemistry and electrometallurgy was held on January 30, at which, in addition to routine matters, plans were discussed for a joint meeting with the Association of Iron and Steel Engineers, to be held at the Belden Hotel, Canton, Ohio, on May 27. The Cleveland and Pittsburgh Sections of the Institute are co-operating in working out plans for this meeting, which will include an inspection trip in the afternoon to be followed by dinner and an even-

ing technical session. (*W. C. Kalb, secretary, committee on electrochemistry and electrometallurgy.*)

STANDARDS ACTIVITIES

A technical session on rating of electrical machinery and apparatus and a technical conference on Canadian and United States standards, both on January 30, and meetings of the standards committee and standards co-ordinating committee 6 on January 28, and of standards co-ordinating committee 4 on January 29, all were held during the winter convention. Reports of some of these activities follow.

Conference on Canadian and American Standards. Feature of the conference was an address on "Wartime Standardization in Canada" by W. P. Dobson, chief testing engineer, Hydro Electric Power Commission of Ontario. High lights of this talk follow:

Standardization work in Canada is carried on by the National Research Council and the Canadian Engineering Standards Association. The former is concerned largely with industrial research but also prepares standards and specifications as a result of its research work, principally in the chemical and textile fields. The Canadian Engineering Standards Association is active in all other fields.

The publications of the Association may be divided into two groups: engineering materials and equipment, and regulations governing construction and operation which may form the basis of laws. Examples of the latter are the Canadian Electrical Code which has reached its fourth edition; and regulations governing radio interference, which are in the course of preparation.

An important responsibility recently assumed by the Association is the approval of electrical equipment sold or used under the Canadian Electrical Code. All approvals in Canada are now issued in the name of the Association; they are used by provincial inspection authorities in the enforcement of sales control regulations, which are in force in nearly all provinces.

The Association receives financial support from the National Research Council which also provides it with office space. Its other sources of revenue are the sale of its publications and subscriptions from industry. In 1940 it received slightly over 50 per cent of its financial support from industry. The approving of electrical equipment is carried on by a division whose finances are separated from the other activities of the Association, and which is entirely supported by the approvals fees received from manufacturers.

Both the Research Council and the Association are at present extremely active in war standardization work. The Council is carrying on many investigations and has prepared specifications for the purchase of a large variety of materials. A few examples are: camouflage nets; linings for bullet-proof helmets, preservative coatings for aircraft, military vehicles; specifications for shoe leathers; the substitution of cotton for linen in parachute harness webbing. It is also calibrating and testing gauges of all kinds.

The Canadian Engineering Standards Association, as a result of decisions reached in 1939 between the British authorities and the Canadian Mission to England, was asked to act as a liaison between the Canadian manufacturers and the British and Canadian governments in the supply of munitions. It performs three distinct services in this capacity: it supplies manufacturers with copies of British specifications and assists in their interpretation; it translates British Standards into Canadian and American practice; it receives from manufacturers and forwards to the Government suggestions for the substitution of Canadian and American standards in British specifications.

For these purposes it has organized since the beginning of the war three committees: on steel, aircraft construction, and electric wire and cable. These committees have saved a great deal of time for the Government and the manufacturers in that through the Canadian Engineering Standards Association it has been possible to co-ordinate the suggestions of the manufacturers and secure prompt consideration of them on the part of the Government authorities.

The American Standards Association and the Canadian Engineering Standards Association have always maintained close contact with each other, and with members of each serving on subcommittees of the other. The present emergency offers opportunities to both associations to assist in the harmonizing of standards and thus speeding up production.

Meeting of Co-ordinating Committee 4. AIEE Standards co-ordinating committee 4 met January 29, during the 1941 winter convention to discuss general principles for rating of electrical apparatus for intermittent or short-time duty cycles. It is proposed that the committee will ultimately prepare a pamphlet on this subject, supplementary to the AIEE No. 1 pamphlet (General Principles Upon Which Temperature Limits Are Based in the Rating of Electrical Machinery and Apparatus) published last June.

The broad objective of the committee is to establish definitions and principles that will enable the short-time or intermittent duty performances of electrical systems to be adequately described. At the present time, methods in use for rating short-time duty apparatus vary widely in the different fields of cables, transformers, motors, and control. Further, methods of rating commonly used do not distinguish clearly between the thermal and other limitations of output.

The output of some electrical apparatus, such as transformers, is limited primarily by thermal considerations, but in most cases other limitations are equally if not more important. For example, the breakdown torque of an induction motor, the commutating limit of a d-c machine, or the slipping torque of the wheels on a locomotive are definite limits of output, which are quite independent of the thermal limits. It is necessary, therefore, to recognize both of these limits in the application of equipment to duty cycle service. The problem is to include these independent factors in the method of rating in such a way as to permit easy correlation of the different elements of a complete system, and at the same time allow definite and simple performance tests.

The discussion in the committee meeting was continued at the session on rating of electrical machinery and apparatus, January 30, where three papers bearing on this subject were discussed. While no definite conclusions were reached, the consensus was that the service-factor method of rating for welding apparatus, proposed by R. C. Freeman and A. U. Welch, represents a distinct forward step, which may be usefully applied to other systems besides welders. In this system, the name-plate rating of the apparatus represents the expected output under short time or intermittent operating conditions. The permissible continuous output is expressed as a product of the name-plate rating by a service factor less than unity, and the performance tests require a continuous heat run at the service-factor rating.

The committee plans to hold another meeting during the summer convention at Toronto. Meanwhile any Institute members who are interested in this question or have suggestions to make are invited to write to the secretary, E. B. Paxton, Standards Department, General Electric Company, Schenectady, N. Y. (*P. L. Alger, chairman, standards co-ordinating committee 4.*)

MEETING OF COMMITTEE ON DOMESTIC AND COMMERCIAL APPLICATIONS

The recently authorized committee on domestic and commercial applications held its first and organization meeting, January 29. J. O'R. Coleman was designated as secretary of the committee, and the following scope was adopted as tentatively approved at an earlier meeting of the technical program committee:

"Treatment of all matters in which the dominant technical factors are the supply and utilization of electric power in domestic premises, such as single or multiple dwellings, garages and other accessory structures, and in commercial premises such as offices, stores, restaurants, banks, and in institutional buildings such as hospitals, schools, libraries, etc. Such subjects as control, interior wiring, heat-operated and motor-operated appliances or equipment for use in domestic, commercial or institutional premises, including elevators and escalators, are properly within this scope. Subjects relating to the production and application of light as such are within the scope of the committee on production and application of light."

The committee has undertaken to sponsor one full technical session and one conference at the summer convention and plans were discussed for the arrangements to be made for these two occasions, especially for the procurement of papers for the technical session, which will probably be devoted largely to the application problems of motor-driven appliances. (*Alexander Maxwell, chairman.*)

MEETING OF COMMITTEE ON PROTECTIVE DEVICES

A meeting of the committee on protective devices was held January 29, 32 members and 5 guests present. The chairmen of the subcommittees on circuit breakers, switches, and fuses; on relays, on lightning arresters, on fault-current limiting devices, and on insulation co-ordination reported on the activities of their various groups. It developed that the committee on protective devices is now working on or following the revision of nine apparatus standards, some of which are ready for release on a trial period basis.

The subjects of temperature rise and ambient temperature came in for considerable discussion as pertaining to apparatus ratings. In connection with Standards No. 27, Switchgear Assemblies, which is now approved for a one-year trial period, the committee adopted the following resolution:

WHEREAS: AIEE Proposed Standard No. 27—Switchgear Assemblies has been approved for publication as a report by both the Protective

Devices Committee and Standards Committee and

WHEREAS: The interpretation of Paragraph 250 and Paragraph 252 has been found not to be clear,

BE IT RESOLVED: The Protective Devices Committee interpret the rules in AIEE Proposed Standard No. 27—Switchgear Assemblies as if the following footnote were added to Paragraphs 250 and 252:

"For test purposes, a temperature rise of 45°C over the outside ambient will be accepted as meeting the requirements of Rule 27-250 and 27-252."

A working group of the subcommittee on circuit breakers, switches, and fuses presented a memorandum on "Dielectric Strength of Oil for Circuit Breaker Testing". This will be put in final form for presentation as a report by the committee.

The Standard for Neutral Grounding Devices was approved and, with some modifications, will be transmitted to the standards committee with the recommendation that it be published for one-year trial use.

The status of the report "Progress in the Art" was given and mention was made of the "Relay Bibliography" which it is expected will shortly be put out in the form of a special publication.

The committee has a comprehensive list of papers which are already prepared or are in the final stages of preparation for future technical sessions. Two sessions were requested for the summer convention at Toronto in June. (*J. R. North, chairman.*)

MEETING OF RESEARCH COMMITTEE

The research committee, meeting January 31, devoted a very busy session particularly to a consideration of research projects of Engineering Foundation for which the Institute acts as sponsor. Reports were received from the advisory committees directing two of these projects and on the basis of these, recommendations are to be made to the board of directors of the Institute. (*W. F. Davidson, chairman.*)

MEETING OF COMMITTEE ON SAFETY

At the meeting of the committee on safety January 29, emphasis was placed on the importance of continued and increased effort to promote safety. Fires and accidents from electrical causes can cause loss of production due to delays in making repairs, loss of electrical and other material and equipment due to destruction, and injury or loss of life of workers. Safe methods of construction, installation, and operation of electrical equipment are well known, but the committee felt that steps should be taken to urge upon the members of the Institute that greater than usual attention be given to the problems.

As steps in this direction, the committee agreed to urge the Student Branches and the Sections to include in meetings which they may sponsor lectures, papers, and motion pictures on various phases of the safety problem.

Information and suggestions were supplied to all the Student Branches early in the autumn of 1940 which it was hoped would guide them in the development of programs on the subjects. Reports received thus far indicate an aroused interest and a larger number of safety discussions in Student Branches on this subject. It was decided to continue the effort this coming autumn by issuing to the Branches a revised bulletin on the subject.

A letter to all the Sections of the Institute encouraged them to include safety among the subjects which they discuss during the current year. Reports indicate that they too are giving more attention to the matter.

Attention of the national technical committees will be called to the importance of consideration of safety problems in connection with the apparatus and problems that come within the scopes of their activities.

The importance of proper maintenance was stressed by the committee as being essential to continued safety. It was pointed out that with all machinery operated at full capacity, in many cases 24 hours per day, the burden upon the electrical equipment is very heavy and failures are likely to increase in number and severity unless there is proper maintenance. Efforts will be made to bring about a greater appreciation of the importance of this problem on the part of users and operators of electrical equipment.

A survey of recent papers dealing with problems involved in the field of safety indicates that additional information is needed on certain subjects. Among these were accurate information on the body resistances and limits of current endurance of farm animals, information which seems to be needed in order to establish a proper basis for determining the principles of safe installation of electrical equipment in barns and elsewhere on farms. (*Frank Thornton, Jr., chairman.*)

Instruments and Measurements Committee Activities Reported at Convention

AT the session on instruments and measurements held at the winter convention on January 31, 1941, T. S. Gray, secretary of the committee presented a detailed report of the committee's scope and accomplishments. Full text of the report follows.

The committee on instruments and measurements, which was organized 24 years ago, has now grown to 35 members with nine subcommittees. The purpose of the committee is to promote and co-ordinate activity in its field. This work includes the review of papers, the arrangement for their presentation at technical sessions, the sponsorship of technical conferences for the discussion of controversial questions, and the preparation of standards, definition, test codes, and reports on the progress of the art in the field of instruments and measurements.

In this report I hope to give you some of the highlights of the work of our committee that goes on behind the scenes. A large part of this work is done by subcommittees. These often include members from other technical committees. Such co-operation is of great importance in the co-ordination of the Institute's activities.

One major work of a subcommittee has been the revision of Standard No. 4 on "The Measurement of Test Voltage in Dielectric Tests." This standard, which was recently completed, describes the methods of measurement of test voltage and of the wave shape of the test voltage used in dielectric tests of electrical apparatus and insulating material. Three classes of tests are included—puncture, flashover, and voltage-proof, using alternating current, direct current, or a surge. The standard includes extensive tables for the spark-over voltages for sphere gaps. It is expected that similar work in other countries eventually may lead to the preparation of a universal standard by the International Electrotechnical Commission.

A second problem in the field of dielectric measurements recently handled by a subcommittee is the preparation of a report on "Wave Form in Dielectric Power-Factor Measurements." This report was published in ELECTRICAL ENGINEERING last year (*EE, June '40, p. 255*). It considers the effect of the wave form used in power-factor measurements on insulating materials and apparatus, and takes up the relative applicability of the terms "form factor", "deviation factor", and "distortion factor" to the specification of the wave form. It recommends that "distortion factor" be used for the specification of the voltage wave form of the power source employed in measurements.

Still a third problem associated with the others on dielectric tests is that of dielectric measurements in the field. A subcommittee is now active on this matter, and a technical conference was held at the last summer convention at Swampscott. Between 50 and 60 Institute members attended, and seven prepared reports were presented.

Dielectric measurements are made in the field to differentiate good insulation from deteriorated insulation, so that the latter may be removed from service before failure occurs and later investigated to determine the possibilities for reconditioning and the cause of the deterioration. More than a million such tests have been made with portable measuring equipment on various types of apparatus. Our subcommittee is engaged in the preparation of a report that will describe the various methods of measurement now in use and give the advantages, disadvantages, and other characteristics of each. It is hoped that this work will result in the formulation of a standard for such measuring equipment in the future.

In another phase of standardization activity, several members of our committee served on a sectional committee of the American Standards Association in the preparation of an American Standard for Electrical Indicating Instruments (No. C-39) published three years ago.

The Institute has a general plan that all of its technical committees shall report periodically on progress in various branches of electrical engineering. In line with that plan, the instruments and measurements committee has been active in the preparation of two such progress reports.

The first of these is a report on "Telemetering and Supervisory Control", which was recently completed by a joint subcommittee of the committees on instruments and measurements and on automatic sta-

Future AIEE Meetings

North Eastern District Meeting
Rochester, N. Y., April 30-May 2, 1941

Summer Convention
Toronto, Canada, June 16-20, 1941

Pacific Coast Convention
Yellowstone National Park, August 27-29, 1941

tions. This report contains a classification of 53 of the numerous types of telemetering and supervisory control equipment now manufactured, a description of each type, and a tabulation of the characteristics of each.

The second progress report is on "Progress in the Art of Metering Electrical Energy", and is now nearing completion. This report differs from others, since no previous progress report has been made on the subject of metering by the Institute. Thus, the scope is much wider, and the development of electrical-energy measurement must be traced from its inception down to the present time. The manuscript is the result of collaboration by authorities in various fields—educational, manufacturing, operating, regulatory, and scientific—although it is necessarily limited in length by the economics of the situation. The manuscript should be completed before the summer convention.

Considerable work is done by our committee in conjunction with, or at suggestion of, other committees. An example is the recent appointment of a subcommittee to prepare a test code on resistance measurement. The writing of test codes for the determination of the performance of electrical apparatus has been one of the most useful standards activities of the Institute during the past few years. It is now expected that our committee will be active in the preparation of several master test codes relating to test methods for measuring certain quantities common to many types of equipment. These measurement test codes are confined to the description of the test methods; the interpretation of the results is left to the test codes on specific types of apparatus. The apparatus test codes will refer to, or incorporate as an integral part, portions of the master code on the methods of measurement.

Other work on test codes has been done recently by a subcommittee working closely with the committee on electrical machinery in the matter of preparing the measurement part of the test codes on transformers, d-c machines, induction machines, and synchronous machines, some of which have already been published.

The formulation of definitions is an important phase of our activity. One subcommittee is reviewing the definitions in a tentative American Standard, and is attempting to correlate these definitions with those in the "Electrical Metermen's Handbook" and the "Code for Electricity Meters."

The differences of opinion and the lively discussion that results when an attempt is made to establish a definition might be surprising to some. An example of the difficulty is the recent criticism of the AIEE definitions of "instrument" and "meter" by a member of the standards committee of another professional society. As you may know, our present definition of "meter" restricts the use of the term to an integrating device such as the watt-hour meter. Ammeters, voltmeters, and wattmeters, which measure the present value of a quantity, are electrical instruments, not meters. A subcommittee has recently been set up to reconsider these definitions and to determine whether or not they should be modified. A great many comments have already been received for consideration by the subcommittee.

Other activities of our committee include a subcommittee to establish suitable methods of stating the performance or accuracy of indicating instruments. The method used at present is to state the accuracy as a percentage of the full-scale indication. This method is not entirely satisfactory because it does not provide for differences in the limiting conditions that exist in the many types of instruments.

Finally, as a means of co-ordination within the Institute, our committee has representatives on the joint subcommittee on electronics, the electrical machinery committee, the standards co-ordinating committee on basic theories and units, and the relay subcommittee of the protective devices committee.

From this brief description I think you can understand, then, that aside from the work of the committee in reviewing papers and in sponsoring sessions at conventions, there is much work done behind the scenes that is of vital importance to the electrical-engineering profession.

Canada Invites AIEE Members to Summer Convention in Toronto

CORDIAL invitations have been extended by Canadian officials to AIEE members to visit Canada and attend the summer convention to be held in Toronto, June 16-20, 1941. For those who attended the summer convention in Toronto in June 1930 nothing further need be said and for those who will attend this year a treat is in store. Vacation opportunities for the tourist and sportsman abound among the rugged scenery, inland waterways, and lakes of Ontario. The Royal York Hotel, convention headquarters, has excellent accommodations and convention facilities.

BORDER REQUIREMENTS ARE SIMPLE

No difficulties are experienced in crossing the Canadian border even during present world conditions. Passports are not required for permanent residents of the United States entering Canada as tourists. As a matter of convenience they should carry identification. The necessary formalities at the border take but a few minutes. Tourists simply report to the Canadian customs officers at the port of entry, answer the necessary questions, and obtain the requisite permit for admission of car and outfit. It is absolutely unnecessary for a tourist entering Canada to pay any fee for an automobile entry permit or its extension. Personal effects "such as are appropriate for the immediate purpose and convenience of the journey" are admitted duty free. Fifty cigars, 200 cigarettes, and two pounds of tobacco in open packages may be brought in free of duty.

Bona fide American citizens have no difficulty in returning across the border. They may possibly be asked by the United States immigration authorities to show papers to establish identity and place of residence. In such case, any of the following personal documents would be useful: birth or baptismal certificate, voter's certificate, tax bills, letter of identification from a bank manager or responsible municipal official, personal letters, car license, driver's license, registration certificate, business identification cards, etc. It is suggested that naturalized citizens carry with them their naturalization certificates.

A premium exists in Canada on United States dollars, and the Foreign Exchange Control Board has made it obligatory for Canadians accepting United States currency in payment for goods and services to pay the premium, which since the beginning of the war has been about ten per cent.

Exchange problems do not exist. The tourist may exchange his currency as he needs it, as a matter of convenience. It is not suggested that money be changed in large quantities. United States currency can be used conveniently at any time and the full rate of exchange will be paid anywhere.

Tourists returning to the United States after a stay of 48 hours or more may take back articles acquired in Canada but not intended for sale in the United States aggregating up to $100 in value. Foodstuffs, cigarettes, tobacco, 100 cigars, and not over one wine gallon of distilled spirits, wines, or malt liquors (provided the quantity is not prohibited by state law) may be included in this exemption. Each member of a family is entitled to this exemption of $100. When husband and wife, or parents and minor or financially dependent children, are traveling together, such exemption may be grouped and allowance made without regard to which member is the owner.

Further information may be had from D. G. Geiger, secretary, general committee, 1941 summer convention, care of The Bell Telephone Company of Canada, Toronto, or from the Canadian Travel Bureau, Ottawa.

SUMMER CONVENTION COMMITTEE

The personnel of the summer convention committee is as follows:

M. J. McHenry, *chairman;* A. H. Frampton, *vice-chairman;* D. G. Geiger, *secretary;* C. B. McWilliam, *treasurer;* A. W. Bradt, C. H. Burchill, E. V. Caton, R. B. Chandler, K. V. Farmer, W. G. C. Gliddon, H. W. Haberl, G. R. Langley, J. H. Steeds, and B. J. O. Strong. *Subcommittee chairmen:* M. J. McHenry, *finance;* T. W. Hill, *publicity;* W. J. Gilson, *entertainment;* T. W. Eadie, *sports;* J. F. Neild, *transportation;* V. G. Smith,

trips; F. F. Ambuhl, *hotel and registration;* O. W. Titus, *women's entertainment;* J. W. Barker, *technical program;* O. W. Titus, *local representative, technical program;* M. S. Coover, *Sections;* and J. M. Thomson, *local representative, Sections.*

Board of Directors Meets During Winter Convention

The regular meeting of the AIEE board of directors was held at the Bellevue-Stratford Hotel, Philadelphia, Pa., on January 30, 1941, during the annual winter convention of the Institute.

Reporting on a subject that had been referred to it by the board of directors, namely, the possibility of a method of transfer to Fellow grade by invitation and recommendations thereon made by the conference of officers, delegates, and members in June 1940, the board of examiners recommended two procedures for transfer to the grade of Fellow: the present procedure, under which transfers are proposed by five Fellows or Members and the application is prepared and signed by the candidate; and an invitational procedure, providing for a preliminary consideration and action by the board of examiners upon submission of the proposal form and an application form, signed by the sponsor, containing a complete statement of the candidate's professional record and experience and the names of the required references. Upon favorable action by the board of examiners, the application form would be submitted to the candidate for his signature, after which it would pass through the present routine procedure for effecting the transfer, that is, recommendation by the board of examiners, posting in ELECTRICAL ENGINEERING, and final action by the board of directors. The board of directors approved the recommendation of the board of examiners providing two procedures for transfer to the grade of Fellow.

Upon recommendation of the chairmen of the publication and technical program committees, the publication committee was authorized to publish as special publications of the Institute, on a self-supporting basis, similar to the Lightning Reference Book previously issued by the Institute, two technical committee reports, one on the subject of telemetering, and the other on relays. The charge for these publications will be determined by a committee consisting of the chairmen of the finance, publication, and technical program committees.

Recommendations of the headquarters committee for renovation of certain rooms at Institute headquarters (foyer, hall, alcove, members' lounge, and board room), were presented and approved, the cost to be met from the property fund for equipment replacements.

Upon petition in the prescribed form and recommendation of the Sections committee, two new Sections of the Institute were authorized, South Bend Section and Arizona Section. (See page 138.) Upon request of the members of the Section and approval by the Sections committee, the board authorized a change in name of the El Paso Section to "New Mexico-West Texas Section".

Upon petition and recommendation of the committee on Student Branches, the board authorized the organization of two new Student Branches of the Institute, namely, Manhattan College Branch, in New York City, and The University of Connecticut Branch, in Storrs, Conn.

Several amendments to the Institute by-laws were adopted. To extend the period of time in which Enrolled Students may apply for admission to the Associate grade without payment of the entrance fee, Sections 53 and 57 were amended to read:

"Sec. 53. The annual Student enrollment fee shall be three dollars ($3.00) payable in advance and shall cover the fiscal year of the Institute beginning on May first. The initial payment upon application for enrollment shall be on the basis of a full year's fee, three dollars ($3.00), or a half year's fee, one dollar and fifty cents ($1.50), depending upon whether the application is filed nearer to May first or November first, respectively. The term of Student enrollment shall not extend beyond the end of the fiscal year (April 30) in which student status ceases, except in those cases where the fiscal year ends within six months after graduation; in those cases Student enrollment may be continued for one additional year. For those students who are not devoting their entire time or a major part of their time to studies, the term of enrollment shall not extend over a period of more than five consecutive years.

Sec. 57. A student must apply for admission to the Associate grade before the first of March of the fiscal year in which his Student enrollment ceases in order to be relieved of the payment of the entrance fee as provided for in the Constitution.

The following new sections were adopted to cover the Charles LeGeyt Fortescue Fellowship committee and the committee on research, recently changed from a technical committee to a general committee:

Sec. 79A. The Charles LeGeyt Fortescue Fellowship committee shall consist of six members appointed by the president, with the appointments confirmed by the board of directors. The committee shall award each year to a student of electrical engineering, who shall have received a baccalaureate degree from a duly recognized technical school in the United States or Canada, a fellowship for postgraduate work in some special field of electrical engineering, in accordance with the regulations prescribed in the bylaws of the committee as approved by the board of directors.

Sec. 84A. The committee on research shall stimulate research of interest to the Institute; shall act on behalf of the Institute, as authorized specifically by the board of directors, to initiate and direct research investigations; shall co-operate, on behalf of the Institute, with departments of national and state governments in the consideration of research investigations; shall submit to the board of directors reports and recommendations concerning research investigations for which financial support from the Institute is sought; shall assist university staffs in selecting research projects for graduate students; and shall assist the technical program committee, as requested, in the preparation of meetings for the discussion of problems in the field of research.

Sec. 65 was amended by the addition of certain general committees not hitherto included and new technical committees, and by the deletion of discontinued committees.

In Memoriam

LEWIS BUCKLEY STILLWELL

THE death of Doctor Lewis Buckley Stillwell, on January 19, 1941, removed from the membership of the Institute its 22d president and a leading pioneer in electric power development who had been rated among the nation's leading electrical engineers during half a century.

After his graduation from Lehigh University in 1885, he became assistant electrician of the Westinghouse Electric and Manufacturing Company. He was chief electrical engineer, 1890–97, and also assistant manager of the company from 1895 to 1897. He directed the layout and design of the first plant of the Niagara Falls Power Company and the Cataract Construction Company at Niagara Falls. In 1897, he became electrical director of the Niagara Falls Power Company. He began his practice as a consulting engineer in New York City in 1900 and filled engagements with many companies on large engineering projects, including the Interborough Rapid Transit Company subway system, the Hudson and Manhattan tubes, and the Holland Tunnel.

Doctor Stillwell made several notable inventions, and was an outstanding leader in the generation, transmission, and distribution of electric power.

He received many honors, including the honorary degree of Doctor of Science from Wesleyan University in 1907, and from Lehigh University in 1914, the AIEE Lamme Medal for 1933, the Edison Medal for 1935, and other medals.

He joined the Institute in 1892, and was transferred to the grade of Member in the same year. He was transferred to the grade of Fellow in 1912. He served on many of the most important Institute committees, and was the author of technical papers of outstanding importance. He was a director, 1896–99, vice-president, 1899–1901, and president, 1909–10.

RESOLVED: That, upon behalf of the membership, the board of directors of the American Institute of Electrical Engineers hereby expresses its appreciation of Doctor Stillwell's many contributions to the development of Institute activities and its keen regret at his death, and be it further

RESOLVED: That these resolutions be entered in the minutes and transmitted to the members of Doctor Stillwell's family.

—AIEE Board of Directors, January 30, 1941

Upon recommendation of the committee on planning and co-ordination, to which had been referred the suggestion for such committee, the board authorized the establishment of a new technical committee of the Institute, to be known as the committee on applications of electricity to therapeutics, to include within its scope all applications of electricity having to do with health, such as sanitation, sterilization, radiation, etc., the exact definition of its scope to be developed by the committee and the technical program committee.

The board voted to appoint an AIEE special committee on national defense.

A recommendation of the committee on air transportation that "the Institute place its facilities at the disposal of the Army-Navy Aeronautical Board, to assist in the development and co-ordination of aeronautical electrical equipment," was presented, and the board approved the recommendation in principle, and instructed the committee to co-operate with the government bureaus.

Approval was given to a recommendation of the chairman of the committee on power generation for the appointment of a joint committee of The American Society of Mechanical Engineers and the AIEE to formulate specifications for prime-mover speed-control devices.

In view of the fact that American Engineering Council terminated its activities on December 31, 1940, Doctor Dugald C. Jackson (chairman) was authorized to continue to act with the other members of the former AEC committee studying the subject of a joint code of ethics for the engineering profession, as a joint committee of the societies concerned to complete the work.

Representatives of the Institute were appointed, as follows:

H. H. Barnes, Jr., reappointed a member of the Hoover Medal board of award for the six-year term beginning in May 1941.

G. L. Knight was appointed to the board of trustees, United Engineering Trustees, Inc., for the four-year term beginning in October 1940.

H. S. Osborne was appointed an additional alternate of the Institute on the Standards Council of the American Standards Association for the year 1941. Appointment of two representatives on the Council of the American Association for the Advancement of Science for the year 1941 was referred to the president with power.

John C. Parker was designated to be recommended for appointment as the Institute's representative on the committee appointed by the Secretary of War to study the protection of civilians in time of war.

C. R. Beardsley was appointed, upon request of the National Council of State Boards of Engineering Examiners, as a representative from the New York Section to serve on the general committee in charge of the 1941 meeting of the NCSBEE, to be held in New York City, October 27–30.

Approval was given to revisions of the rules for the award of AIEE District prizes which were recommended by the chairman of the committee on award of Institute prizes. These revisions provided that previous presentation of an undergraduate student paper shall not bar the subsequent award of an initial paper prize, and changed the closing date for the receipt of papers for District prize awards from February 15 to February 1.

The board, by rising vote, adopted a resolution in memory of Past President Lewis B. Stillwell, who died on January 19, 1941. (See page 135.)

The board directed that an expression of its sincere appreciation of the excellent arrangements made for the 1941 winter convention, in Philadelphia, and the gratifying success attained, be transmitted to the winter convention committee.

Actions relating to Institute meetings were taken, as follows:

A resolution was adopted to the effect that the 1941 annual meeting of the Institute will be held in Toronto, Ontario, on Tuesday, June 17. Dates were approved for the previously authorized South West District meeting in St. Louis—October 8–10, 1941; and for the previously authorized Southern District meeting in New Orleans—December 3–5, 1941. The Great Lakes District meeting, which was to have been held in Fort Wayne, Ind., in April 1941, was postponed indefinitely, upon recommendation of the District executive committee.

The following schedule of national conventions and District meetings for 1942, as prepared and submitted by the committee on planning and co-ordination, was adopted:

Winter convention, New York, N. Y., January 26–30

Summer convention, Chicago, Ill., June 22–26

North Eastern District meeting, Schenectady, N. Y., early in May

Middle Eastern District meeting, Pittsburgh, Pa., in the fall

Other actions taken by the board included the following:

Minutes of the meeting of the board of directors held on October 25, 1940, were approved.

Actions of the executive committee on applications for transfer, election, and Student enrollment were reported and confirmed, as follows: As of November 19, 1940—8 applicants transferred to grade of Fellow, 10 applicants transferred and 10 elected to the grade of Member, 47 applicants elected to the grade of Associate, 561 Students enrolled. As of December 23, 1940—4 applicants transferred to the grade of Fellow, 13 applicants transferred and 8 elected to the grade of Member; 68 applicants elected to the grade of Associate; 488 Students enrolled.

Reports were presented and approved of meetings of the board of examiners held November 14 and December 19, 1940, and January 23, 1941. Upon recommendation of the board of examiners, the following actions were taken: 1 applicant was transferred to the grade of Fellow; 16 applicants were transferred and 15 were elected to the grade of Member; 74 applicants were elected to the grade of Associate; 130 Students were enrolled.

Monthly expenditures were reported by the finance committee and approved by the board, as follows: $24,827.28 for November 1940, $24,194.64 for December 1940, and $22,293.89 for January 1941.

Those present were:

President—R. W. Sorensen, Pasadena, Calif.

Past President—F. Malcolm Farmer, New York, N. Y.

Vice-Presidents—J. W. Barker, New York, N. Y.; K. L. Hansen, Milwaukee, Wis.; H. W. Hitchcock, Los Angeles, Calif.; C. T. Sinclair, Pittsburgh, Pa.; A. LeRoy Taylor, Salt Lake City, Utah; J. M. Thomson, Toronto, Ont.; A. L. Turner, Omaha, Nebr.

Directors—T. F. Barton, C. R. Beardsley, New York, N. Y.; M. S. Coover, Ames, Iowa; Mark Eldredge, Washington, D. C.; R. E. Hellmund, East Pittsburgh, Pa.; F. H. Lane, Chicago, Ill.; F. J. Meyer, Oklahoma City, Okla.; D. C. Prince, Schenectady, N. Y.; R. G. Warner, New Haven, Conn.

National Treasurer—W. I. Slichter, New York, N. Y.

National Secretary—H. H. Henline, New York, N. Y.

Nominating Committee Announces Official Candidates for 1941

A complete official ticket of candidates for the Institute offices that will become vacant August 1, 1941, was selected by the national nominating committee at its meeting held in Philadelphia, Pa., January 27, 1941. This committee, in accordance with the constitution and bylaws, consists of 15 members, one selected by the executive committee of each of the 10 geographical Districts, and 5 selected by the board of directors from its own membership. The following members were present:

A. S. Anderson, Denver, Colo.; T. F. Barton (alternate), New York, N. Y.; C. R. Beardsley, New York, N. Y.; M. S. Coover, Ames, Iowa; W. E. Crawford (alternate), Milwaukee, Wis.; C. L. Dawes, Cambridge, Mass.; J. F. Fairman, New York, N. Y.; A. H. Frampton, Toronto, Ont.; F. E. Johnson, Jr., New Orleans, La.; L. R. Mapes, Chicago, Ill.; C. W. Mier, Dallas, Tex.; R. F. Monges (alternate), Berkeley, Calif.; W. B. Morton, Philadelphia, Pa.; H. E. Murdock, Bozeman, Mont.; D. C. Prince (alternate—for a part of the meeting), Schenectady, N. Y.; and H. H. Henline, secretary of the committee.

Following is the list of official candidates selected by the committee:

FOR PRESIDENT

David C. Prince, manager, commercial engineering department, General Electric Company, Schenectady, N. Y.

FOR VICE-PRESIDENTS

N. S. Hibshman, associate professor of electrical engineering, Lehigh University, Bethlehem, Pa. (Middle Eastern District, number 2)

J. Elmer Housley, superintendent of power, Alumi-

Membership—

Mr. Institute Member:

Thank you for your co-operation. The response of members to our appeal was gratifying indeed. Your help, together with the hard work of Section membership committees in interviewing persons suggested by you as eligible for membership, has produced results.

New applications received, six months ending January 31, 1941	618
New applications received, six months ending January 31, 1940	601

Those of you who did not send in the names of eligible prospects for membership among your acquaintances can make up for it by doing so now. Telephone or mail them direct to the chairman of your Section membership committee. His name and address are given on page 33 of the January issue of ELECTRICAL ENGINEERING.

O. C. Brill

Chairman, National Membership Committee

num Company of America, Alcoa, Tenn. (Southern District, number 4)

Arthur L. Jones, commercial vice-president and district manager, General Electric Company, Denver, Colo. (North Central District, number 6)

Walter C. Smith, engineer of Pacific district, General Electric Company, San Francisco, Calif. (Pacific District, number 8)

C. A. Price, chief engineer, Canadian Westinghouse Company, Ltd., Hamilton, Ontario, Canada. (Canada District, number 10)

FOR DIRECTORS

Lester R. Gamble, electrical engineer, Washington Water Power Company, Spokane, Wash.

T. G. LeClair, supervising development engineer, Commonwealth Edison Company, Chicago, Ill.

Fred R. Maxwell, Jr., professor of electrical engineering, University of Alabama, University, Ala.

FOR NATIONAL TREASURER

W. I. Slichter, professor and head of Department of Electrical Engineering, Columbia University, New York, N. Y.

The constitution and bylaws of the Institute provide that the nominations made by the national nominating committee shall be published in the March issue of ELECTRICAL ENGINEERING. Provision is made for independent nominations as indicated in the following excerpts from the constitution and bylaws:

CONSTITUTION

Sec. 31. Independent nominations may be made by a petition of twenty-five (25) or more members sent to the national secretary when and as provided in the bylaws; such petitions for the nomination of vice-presidents shall be signed only by members within the District concerned.

BYLAWS

Sec. 23. Petitions proposing the names of candidates as independent nominations for the various offices to be filled at the ensuing election, in accordance with Article VI, Section 31 (Constitution), must be received by the secretary of the national nominating committee not later than March 25 of each year, to be placed before that committee for the inclusion in the ballot of such candidates as are eligible.

On the ballot prepared by the national nominating committee in accordance with Article VI of the Constitution and sent by the national secretary to all qualified voters during the first week in April of each year, the names of the candidates shall be grouped alphabetically under the name of the office for which each is a candidate.

(*Signed*) National Nominating Committee
by H. H. Henline, *Secretary*

BIOGRAPHICAL SKETCHES OF NOMINEES

In order that those not personally acquainted with the nominees may know something of them and their qualifications for the Institute offices for which they have been nominated, brief biographical sketches are given in the "Personals" columns of this issue.

AIEE Broadcast Series Ends

The final broadcast of the series currently sponsored by the AIEE on the role of electrical engineers in national defense (*EE, Jan. '41, p. 86*) is being presented March 4, 1941, from 10:15 to 10:30 p.m., with Doctor F. B. Jewett, vice-president, American Telephone and Telegraph Company, and Doctor Karl T. Compton, president, Massachusetts Institute of Technology, discussing electrical research in relation to defense. Presented on the Blue Network stations of the National Broadcasting Company, the series was arranged by the company's educational division.

Four broadcasts during February continued the series, which began with a program from Philadelphia, January 27, in connection with the AIEE winter convention, on the enlistment of the electrical-engineering profession for defense. In addition to well-known engineers, an anonymous "Mr. Jones"—"one of the 130,000,000 who are being defended"—took part in each of the programs.

The second broadcast, on February 3, dealt with the work of electrical engineers in the Army, in an interview with General J. O. Mauborgne, chief signal officer, United States Army. Monday, February 10, Commander E. W. Mills, Bureau of Ships, United States Navy Department, told how the resources of electrical engineers are utilized in the Navy. Assisting in the discussion was Joseph W. Barker, dean of engineering, Columbia University. Activities of electrical engineers in the defense industries were described by Marvin W. Smith, vice-president of the Westinghouse Electric and Manufacturing Company, and R. C. Muir, vice-president of the General Electric Company, on Tuesday, February 18. The broadcast of Tuesday, February 25, covered the mobilization of the nation's electric power facilities for defense. C. W. Kellogg, president of the Edison Electric Institute, and a member of the Advisory Committee to the Council of National Defense, and Dean Edward L. Moreland, Massachusetts Institute of Technology, led the discussion.

COMMENTS WANTED

As this broadcasting venture is of the nature of an experiment for AIEE, the committee in charge would like especially to receive comments and suggestions from interested members concerning the effectiveness of the series just closing, or possibilities for further programs in the future. Address such comments to the national secretary, AIEE headquarters, 33 West 39th Street, New York, N. Y.

District • • • •

North Eastern District Meeting to Be Held at Rochester, N. Y.

A three-day meeting of the North Eastern District will be held in Rochester, N. Y., April 30–May 2, 1941, with headquarters in the Sagamore Hotel.

The program tentatively arranged consists of four technical sessions, two student, and one general session, with a stag party on Wednesday evening, and a banquet on Thursday evening. The papers to be presented in the four technical sessions deal with work in the fields of communication, central stations, technical photography, measurements, dielectrics, electrical machinery, and industrial power applications. Addresses by well-known speakers on timely subjects of interest to many members will be arranged for the general session and the banquet will be addressed by Doctor Alan Valentine, president of the University of Rochester, and R. W. Sorensen, President, AIEE.

An interesting program of events for women guests will be provided and all members are especially urged to bring their wives to the meeting.

District 7 Executive Committee Meets at Dallas

The executive committee of the AIEE South West District met at Dallas, Tex., November 29, 1940, with an attendance of the following Section and other representatives:

J. L. Hamilton, AIEE vice-president, District 7
L. L. Crump, secretary, District 7
J. S. Johnson, chairman, committee on student activities
L. O. Campbell, national membership committee
F. A. Decker, El Paso Section
I. W. Best, El Paso Section
L. H. Mathes, Houston Section
P. H. Underwood, Houston Section
R. R. Miner, Wichita Section (representing P. S. Colby and R. B. Gow)
P. C. Ellis, Kansas City Section
G. K. Shirling, Kansas City Section
J. S. Malsbary, St. Louis Section
J. W. Shawver, Oklahoma City Section
W. B. Stephenson, Oklahoma City Section
H. P. Dougherty, Tulsa Section
W. F. Pinckert, San Antonio Section
Eugene Dissett, San Antonio Section
Gibbs Dyer, North Texas Section (representing H. R. Pearson)
G. H. Pingree, North Texas Section

Action taken by the committee included the election of C. W. Mier, Dallas, Tex., to serve on the national nominating committee, and approval of the appointment of F. A. Decker, H. R. Pearson, R. B. Gow, and W. B. Stephenson to the District coordinating committee.

The problems created by conscription in regard to the transfer of Enrolled Students to Associate membership in the Institute and the payment of Institute dues during military service were discussed by the committee at the suggestion of Chairman J. S. Johnson of the District committee on student activities. The committee voted that the Institute board of directors be requested to consider these problems and take action. This request was submitted to the board in a letter embodying the committee's belief that special provision during the draft period should be made for Students and probably for regular Institute members as well.

Report of activities were presented for all the Sections in District 7, and a general discussion followed. A student meeting is planned for the spring of 1941, to be held at one of the colleges, Chairman Johnson announced. He suggested that a committee be appointed to arrange for student attendance at the District meeting to be held at St. Louis, October 8–10. Plans for the District meeting and national affairs of interest to the District were discussed by Vice-President J. L. Hamilton.

Great Lakes District Meeting Postponed

Indefinite postponement of the Great Lakes District meeting heretofore scheduled to be held in Fort Wayne, Ind., April 23–25, was authorized by the AIEE board of directors at its winter-convention meeting January 30 in Philadelphia. This action was taken upon recommendation of the District committee in charge of the meeting and of the District executive committee. The action reflects the increasing industrial pressure incidental to the national defense program.

Branch • • • •

New Branches Authorized

Organization of two new Student Branches of the Institute was authorized at the meeting of the board of directors January 30, 1941, upon petition and recommendation of the committee on Student Branches. The new Branches are Manhattan College Branch, New York, N. Y., and the University of Connecticut Branch, Storrs, Conn. The total number of AIEE Student Branches is now 124.

Section • • • •

Pittsburgh Section Holds Student Branch Conference

Record attendance of 292, of which 95 were students, is reported for the joint mid-winter meeting and Student Branch conference held January 14, 1941, at Pittsburgh, Pa., by the AIEE Pittsburgh Section and the Electrical Section of the Engineers Society of Western Pennsylvania. The program included a student technical session, an inspection trip to the Copperweld Steel Company plant at Glassport, Pa., and a dinner meeting at which President Royal W. Sorensen was guest of honor. Other speakers at the dinner, at which Chairman G. R. Patterson of the Pittsburgh Section presided, were National Secretary H. H. Henline, District 2 Vice-President C. T. Sinclair, Doctor Charles S. Tippetts, dean of school of business administration, University of Pittsburgh, and M. S. Trimble, chairman, Carnegie Institute of Technology Branch, who reported on the Branch conference. The following papers were presented at the technical session, at which Otto Kebernik, chairman, University of Pittsburgh Branch, presided:

VOLTAGE REGULATOR TUBES, J. M. Pomfrett, Pennsylvania State College

DESIGN OF ELECTRONIC MUSICAL INSTRUMENTS, John Jenkins, Carnegie Institute of Technology

THE ENGINEER'S NEED FOR CULTURAL DEVELOPMENT, E. S. Reeser, West Virginia University

THE ELECTRON MICROSCOPE, W. P. Smith, University of Pittsburgh

Arizona and South Bend Sections Being Formed

In response to local petitions and in furtherance of the Institute's general policy of placing all parts of the United States within the territory of some Section, two new Sections received the authorization of the AIEE board of directors at its meeting January 30, 1941, and are in process of organization. These are the Arizona Section and the South Bend Section. The territory of the former includes the entire state of Arizona. The South Bend Section includes LaPorte and Porter Counties, Indiana, formerly in the territory of the Chicago Section; and Elkhart and St. Joseph Counties, Indiana, and Berrien County, Michigan, formerly in the territory of the Fort Wayne Section.

These new Sections bring the Institute's total to 72 Sections. Only some 90-odd members in the United States now will be located outside the territory of some Section.

The board also authorized changing the name of the El Paso Section to "New Mexico-West Texas Section", as requested by members of the Section.

Standards • • •

Standards on Conduction in Vacuum, Gases, Liquids, and Solids

A new AIEE standards co-ordinating committee (number 7) on conduction in vacuum, gases, liquids, and solids has been appointed, with R. E. Hellmund as chairman. Because of the very broad scope of the work of this committee, it has been considered advisable to follow the practice which has been found advantageous in the organization of some of the other co-ordinating committees; namely, to appoint a steering committee, the function of which is to appoint subcommittees of specialists for handling specific projects and to guide these subcommittees in their work. Various projects will be taken up from time to time in this manner, as the need for them arises, or as it becomes evident that worthwhile service can be rendered to the profession by such activities.

(For other matters relating to standards, see pages 132 and 147.)

Personal • • •

D. C. Prince Nominated for Institute President

David Chandler Prince (A'16, F'26) manager of the commercial engineering department, General Electric Company, Schenectady, N. Y., has been nominated for the presidency of the AIEE for the 1941–42 term. He was born February 5, 1891, at Springfield, Ill., and received the degrees of bachelor of science in electrical engineering, 1912, and master of science in electrical engineering, 1913, from the University of Illinois. Following graduation he spent a year with General Electric at Schenectady, in the test course and on special problems. From 1914 to 1917 he was employed on valuations and rate-making by the Illinois State Public Utilities Commission and from 1917 to 1919 was a first lieutenant in the ordnance department of the United States Army, where he was attached to Air Service headquarters in Paris, France. He returned to General Electric in 1919 and during the following year served as a special representative in Poland. He was appointed a research engineer in the radio department in 1920, and in 1923 was assigned to the research laboratory, first on vacuum-tube applications and later as head of the power control section. He was transferred to Philadelphia in 1929 as research engineer of the switchgear department. He was chief engineer of the Philadelphia plant from 1931 to 1940, when he was given his present appointment. He is the author of many technical papers and articles, is co-author of two books, and holder of 76 patents. He was honored in 1940 as a "modern pioneer" by the National Association of Manufacturers. He is at present a director of the Institute and a member of the Edison Medal, Fortescue Fellowship, transfers, protective devices, and air transportation committees, and has also been a member of the board of examiners (1938–40), finance committee (1938–40), and Lamme Medal committee (1936–39). He is a past chairman of the Philadelphia Section.

Vice-Presidential Nominees Are Hibshman, Housley, Jones, Smith, and Price

Nelson Sherk Hibshman (A'27, M'32) associate professor of electrical engineering, Lehigh University, Bethlehem, Pa., has been nominated for vice-president of the AIEE Middle Eastern District (2). He was born at Harrisburg, Pa., January 20, 1902, and received the degree of bachelor of science in electrical engineering from Pennsylvania State College in 1924, and that of master of science from Lehigh University in 1927. He entered the department of electrical engineering at Lehigh in 1927 with the rank of assistant professor, later becoming associate professor. He has also been employed at various times in the steel,

D. C. PRINCE

N. S. HIBSHMAN

J. E. HOUSLEY

automotive, telephone, and electrical manufacturing industries, and has published researches in rectification machinery and electric arc welding. He is at present serving on the staff of the regional adviser for engineering defense training. He has served the Institute as chairman of the Lehigh Valley Section, counselor of the Lehigh Student Branch, and a member of the committee on instruments and measurements. He is a member of Eta Kappa Nu, Tau Beta Pi, and Sigma Xi.

John Elmer Housley (A'19, M'39) superintendent of power, Aluminum Company of America, Alcoa, Tenn., has been nominated for vice-president of the AIEE Southern District (4). He was born at Knoxville, Tenn., January 9, 1893, and received the degree of bachelor of science in electrical engineering from the University of Tennessee in 1915. The same year he was employed by the Aluminum Ore Company, East St. Louis, Ill., as engineer apprentice, becoming electric shop foreman in 1916, electrical engineer in 1917, and assistant superintendent of power in 1921. In 1922 he became a sales engineer for the Aluminum Company of America, with headquarters at Kansas City, Mo., and the following year returned to the Aluminum Ore Company on special engineering work. In 1924 he became assistant district electrical superintendent of the Tallahassee Power Company, Alcoa, and in 1927 superintendent of power of the Aluminum Company of America. He is a member of the Institute's committee on electrochemistry and electrometallurgy, vice-chairman of District 4, and a past chairman of the East Tennessee Section. He has written a number of technical articles.

Arthur Lucas Jones (A'07, M'26, F'38) commercial vice-president and district manager, General Electric Company, Denver, Colo., has been nominated for vice-president of the AIEE North Central District (6). He was born May 22, 1879, at Ballston, N. Y., and received the degree of mechanical engineer from Cornell University in 1904. He entered the test department of the General Electric Company at Schenectady, N. Y., in 1904, and in 1907 was transferred to the power and mining engineering department. In 1909 he was sent to the Denver office as district engineer of the Rocky Mountain district. He was appointed assistant district manager in 1926, district manager in 1928, and in 1936 was appointed commercial vice-president, continuing the duties of district manager. He is a past chairman of the Denver Section.

Walter Charles Smith (A'07, M'26, F'40) district engineer, Pacific district, General Electric Company, San Francisco, Calif., has been nominated for vice-president of the AIEE Pacific District (8). Born January 9, 1882, at Clarkston, Mich., he received the degree of bachelor of science in electrical engineering at the University of Michigan in 1905. Shortly after graduation he entered the test department of the General Electric Company at Schenectady, N. Y., and in 1907 was transferred to the transformer engineering department. The following year he was transferred to Pittsfield, Mass., continuing there until 1918, in the transformer and distribution transformer engineering departments. He was engaged in special investigation work for the transformer department, with headquarters at the company's Denver, Colo., office, from 1918 to 1920, when he became sales engineer at the San Francisco office. He was made assistant engineer of the latter office in 1931 and in 1932 became chief engineer, a position he held until his appointment as district engineer at the beginning of 1941. He received a Coffin Award in 1925 for "ingenious design of combined transformer and autotransformer". He is a past chairman of the Pittsfield Section and of the San Francisco Section, and is a member of the committee on principles of professional conduct.

Clarence Albert Price (A'19, M'39) chief engineer, Canadian Westinghouse Company, Ltd., Hamilton, Ont., Canada, has been nominated for vice-president of the AIEE Canada District (10). He was born at Crumlyne, Pa., October 13, 1875, and studied mechanical arts and electrical engineering at Drexel Institute, graduating in 1898. He spent some months in general work on electrical apparatus before becoming laboratory assistant in the insulated wire department of John A. Roebling Sons Company, Trenton, N. J., in 1900. In 1901 he was employed by the Bell Telephone Company of Philadelphia, Pa., and in 1902 became an engineering apprentice with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. He was engaged on induction motor design at East Pittsburgh from 1904 until 1906, when he was transferred to Canadian Westinghouse in the same capacity. He became assistant chief engineer of that company in 1919 and has been chief engineer since 1936. He is a past chairman of the Toronto Section.

A. L. JONES

W. C. SMITH

C. A. PRICE

Gamble, Le Clair, and Maxwell Nominated for Institute Directorships

Lester Raymond Gamble (A'23, M'28, F'39) engineer in charge of the electrical department, Washington Water Power Company, Spokane, Wash., has been nominated for membership on the AIEE board of directors. Born at Carter, Wyo., November 24, 1888, he received the degree of bachelor of science in electrical engineering from Purdue University in 1914. Following graduation he was employed as a lineman by the Utah Light and Traction Company (later Utah Power and Light Company), Ogden, and in 1915 was transferred to Salt Lake City as a draftsman. He was appointed assistant distribution engineer in 1916. He was a captain in the Engineer Corps of the United States Army 1917–19, during which time he supervised the construction of buildings, transmission lines, and distribution systems in France. In 1919 he returned to his former position with the Utah Power and Light Company where he continued until 1923. He then became engineer in the distribution department of the Washington Water Power Company, and in 1925 was made assistant electrical engineer. Since 1933 he has been electrical engineer in charge of the company's electrical department and construction budget. During 1925–26 he directed an electric-range survey for the National Electric Light Association and made a report of the findings. He was vice-president of the North West District 1938–40, is a member of the standards committee and was a member of the committee on production and application of light (1938–40), and is a past chairman of the Spokane Section.

Titus George Le Clair (A'24, M'29, F'40) supervising development engineer, Commonwealth Edison Company, Chicago, Ill., has been nominated for membership on the AIEE board of directors. He was born at Superior, Wis., August 26, 1899, and received the degree of bachelor of science in electrical engineering from the University of Idaho in 1921. He spent a year and a half as student engineer with General Electric Company, Schenectady, N. Y., before entering the employ of Commonwealth Edison Company in 1923 as a cable engineer. He was transferred to the inside plant department as substation field engineer the following year and in 1927 became engineer of system protection. In 1930 he became a staff engineer in the office of the chief electrical engineer, in 1932 was made development engineer, and since 1936 has been supervising development engineer. He holds patents on several inventions and is the author of technical papers and articles. He is a member and trustee of the Western Society of Engineers. He is a member of the AIEE committees on professional development and on legislation affecting the engineering profession, and was a member of the membership commit-

tee (1930–35). He is a past chairman of the Chicago Section.

Frederick Richard Maxwell, Jr. (M'30) professor of electrical engineering, University of Alabama, Tuscaloosa, has been nominated for membership on the AIEE board of directors. He was born at Tuscaloosa, June 15, 1889, and received the degrees of bachelor of science, 1911, mechanical engineer, 1912, and electrical engineer, 1923, from the University of Alabama. In 1913 he was employed on plant operation by the Tuscaloosa Ice and Light Company, later the Tuscaloosa Railway and Utilities Company, and in 1916 was made commercial manager. After two years (1917–19) in the United States Naval Reserve, he returned to the company as assistant general manager. In 1920 he became instructor in electrical engineering and physics at the University of Alabama, becoming assistant professor the following year, associate professor in 1923, and full professor in 1934. He is at present vice-president of the AIEE Southern District, and a member of the committee on electrochemistry and electrometallurgy, and has been chairman of the Alabama Section, vice-chairman of the District, and counselor of the University of Alabama Student Branch. He is a member of the Society for the Promotion of Engineering Education and of Tau Beta Pi.

W. I. Slichter Renominated as Institute Treasurer

Walter Irvine Slichter (A'00, M'03, F'12) professor and head of the department of electrical engineering, Columbia University, New York, N. Y., has been renominated to serve as treasurer of the AIEE. He has held the position of national treasurer since 1930, and has also served as a manager (1918–22), vice-president (1922–24), and member of many standing and special committees. He is at present a member of the executive, Edison Medal, Fortescue Fellowship, Columbia University scholarships, constitution and bylaws, and land transportation committees; represents the Institute on the boards of the Engineering Societies Library and the Engineering Foundation, the advisory board of the National Bureau of Engineering Registration, and the Engineering Societies Monographs committee; and is chairman of the special committee on pension plans. A biographical sketch of Professor Slichter appeared in the March 1937 issue, page 136.

C. A. Adams to Receive Lamme Medal for 1940

Comfort Avery Adams (A'94, M'05, F'13) consulting engineer, Edward G. Budd Manufacturing Company, Philadelphia, Pa., has been awarded the AIEE Lamme Medal for 1940 "for his contributions to the theory and design of a-c machinery and his work in the field of electric welding." He was born at Cleveland, Ohio, November 1, 1868, and received the degree of bachelor of science in 1890 from the Case School of Applied Science and that of electrical engineer in 1905 from Harvard University. He also received the honorary degree of doctor of engineering from Harvard in 1925, and from Lehigh University in 1939. During the summer of 1890 he went with the Reid Expedition to Alaska making magnetic and meteorological observations and for the following year was a draftsman for the Brush Electric Company, Cleveland. He became an instructor in electrical engineering at Harvard University in 1891 and continued as a member of the Harvard faculty, as assistant professor, 1896–1906, professor, 1906–16, Lawrence professor of engineering, 1914–36, dean of the engineering school, 1919–21, until his retirement from teaching in 1936, when he was made professor emeritus. In addition to teaching, he carried on an extensive consulting practice on which he has concentrated since 1936. In addition to the Budd company, his connections include the Babcock and Wilcox Company, Okonite Company, and others. He has served the Institute as a manager (1912–15), vice-president (1915–17), and president (1918–19), and as member or chairman of many committees, and has represented the Institute on various bodies. He is at present a member of the standards committee, and chairman of the welding research committee of the Engineering Foundation. He was one of the organizers and first chairman of The American Engineering Standards Committee, from which the American Standards Association grew. He was the first president of the American Welding Society, and is also a member of the American Academy of Arts and Sciences, American Association for the Advancement of Science, American Physical Society, Society for the Promotion of Engineering Education, American Society of Civil Engineers, American Society of Mechanical Engineers, American Society of Testing Materials, and of several foreign technical societies.

L. R. GAMBLE

T. G. LE CLAIR

F. R. MAXWELL, JR.

C. A. ADAMS

Obituary • • •

Lewis Buckley Stillwell (A'92, M'92, F'12, past president) consulting engineer, Princeton, N. J., died January 19, 1941, at Baltimore, Md. He was born March 12, 1863, at Scranton, Pa., studied at Wesleyan University 1892–94, and received the degree of electrical engineer, 1885, from Lehigh University, and the honorary degrees of master of science, 1907, and doctor of science, 1914, from Lehigh University, and that of doctor of science, 1907, from Wesleyan University. He entered the employ of the Westinghouse Electric and Manufacturing Company at Pittsburgh, Pa., in 1886, as assistant electrician, and in1891 was appointed chief electrical engineer. His contributions, as Westinghouse engineer, to the design of the first plant of the Niagara Falls Power Company, Niagara Falls, N. Y., led to his appointment in 1897 as electrical director of that company. In 1900 he began practice as a consulting engineer in New York, N. Y., serving on a number of important engineering projects, notably in connection with railway and urban transit electrification. A leader in the development of alternating current and in the establishment of standard frequencies, he was the author of a number of inventions, including the Stillwell regulator, the time-limit circuit breaker, and the diagrammatic pilot control switchboard. He served the Institute as a director (1896–99), a vice-president (1899–1901), and president (1909–10), and was active on many committees. He was also a past president of the American Institute of Consulting Engineers, a past vice-president of American Engineering Council, and past chairman of Engineering Foundation, and was also a member of the American Society of Civil Engineers, National Academy of Sciences, American Philosophical Society, Franklin Institute, Institution of Electrical Engineers, and Royal Society of Arts, Great Britain. He was awarded the Niagara Medal by the Niagara Falls Power Company in 1899; a medal for "leadership as chairman of Engineering Foundation in consolidating the research work of the Foundation and the founder societies" presented by the

ASCE in 1929; the AIEE Lamme Medal in 1933, and the Edison Medal for 1935. He was a life trustee of Princeton University.

Henry Jones Blakeslee (A'02, M'15) president, The States Company, Hartford, Conn., died January 19, 1941. He was born at Hartford August 15, 1876, and received the degrees of bachelor of science in 1898 and master of science in 1902 from Trinity College. From 1898 to 1900 he was an instructor at Trinity College, Hartford, and for the next three years superintendent of construction for the Hartford Electric Light Company. In 1903 he became electrical inspector for the New England Insurance Exchange, and later for the Underwriters Association of New York State, before becoming electrical engineer and superintendent of the Bureau of Gas and Electricity, City of Syracuse, N. Y., a position which he held from 1907 to 1913. He was one of the founders of The States Company, which was organized in 1911, and first served as treasurer and electrical engineer, later becoming president. He held a number of patents on meter-testing equipment, and was honored in 1940 as a "modern pioneer" by the National Association of Manufacturers.

William Henry Capen (M'23) assistant vice-president and assistant general technical director, International Telephone and Telegraph Corporation, New York, N. Y., died at Orange, N. J., January 15, 1941. He was born August 13, 1890, at Newton, Mass., and received the degrees of bachelor of science, 1913, and master of electrical engineering, 1914, from Harvard University. He entered the employ of Western Electric Company, Inc., New York, N. Y., in 1914, where he specialized in transmission problems. In 1922 he went to Japan as consulting transmission engineer for the company. In 1924 he was transferred to International Western Electric Company, which was later taken over by the International Telephone and Telegraph Corporation. From 1926 to 1929 he was engaged on foreign assignments, including the development of the Japanese telephone system and installation of communications systems for various European governments. Since 1929 he had been assistant vice-president and assistant technical director. He had written technical books and articles.

Charles Austin Greenidge (A'03, M'06, F'13) retired vice-president and chief engineer, Utility Management Corporation, died January 23, 1941, at Cooperstown, N. Y. He was born October 5, 1872, Barbados, British West Indies, and received the degree of mechanical engineer from Stevens Institute of Technology in 1895. In 1896 he was employed by the Mount Morris Electric Company, New York, N. Y., as tester, later becoming acting superintendent. When in 1899 the company was merged into the New York Edison Company, he was appointed assistant district superintendent. He became superintendent of the electric department, Equitable Gas and Electric Company, Utica, N. Y., in 1901, and of the Utica gas and Electric Company in 1902, becoming general manager of the electric department in 1905. About 1910 he became associated with the J. G. White Management Corporation, New York, N. Y., becoming electric lighting manager and later chief engineer. He continued in that position for many years, becoming vice-president of the Utility Management Corporation about 1930. He had retired in 1939.

Daniel M. Wise (M'37) staff supervisor, plant engineering department, American Telephone and Telegraph Company, Philadelphia, Pa., died January 8, 1941. He was born January 29, 1888, at Williamsport, Pa., and received the degree of bachelor of science in electrical engineering from Bucknell University in 1912. He was employed as laboratory assistant, United States Geological Survey, Washington, D. C., and as student apprentice at Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., before becoming magnetic observer for the Carnegie Institution of Washington, D. C., in 1913. He took part in expeditions to Canada, Africa, and South America, and in solar-eclipse expeditions to Lakin, Kans., and Sobral, Brazil, having charge of the latter expedition. He joined the American Telephone and Telegraph Company in 1920, first as an engineer in the long lines department at Harrisburg, Pa., and since 1926 at Philadelphia, where he was division transmission engineer in the long lines department from 1927 to 1940.

Charles Roy Higson (A'21, M'32) consulting engineer, Utah Power and Light Company, Salt Lake City, Utah, died December 18, 1940. He was born August 29, 1883, at Salt Lake City, and received the degrees of bachelor of science, 1907, and electrical engineer, 1911, from the University of Wisconsin. He spent a year in the test department of General Electric Company, Schenectady, N. Y., before becoming an instructor in electrical engineering at the University of Wisconsin, Madison, where he remained until 1911. He entered the operating department of the Utah Light and Traction Company, predecessor of the Utah Power and Light Company, in 1911, and became assistant engineer of the latter company in 1918. He served as superintendent of distribution from 1925 until 1940. He was AIEE vice-president 1932–34, a past chairman of the Utah Section and past president of the Engineering Council of Utah.

Ulrich Joseph Rappel (M'35) professor and head of the department of electrical engineering, University of Dayton, Dayton, Ohio, died September 24, 1940, according to information just received. He was born December 18, 1880, at Chicago, Ill., and received the degrees of bachelor of arts, 1902, and master of arts, 1905, from the University of Dayton, and those of master of science, 1907, and doctor of philosophy, 1909, from the University of Fribourg, Switzerland. He was an assistant in physics at the latter institution 1907–09, and went to the University of Dayton in 1909 as professor of physics. He had headed the electrical-engineering department since 1913. He was also a member of the American Association for the Advancement of Science, Illuminating Engineering Society, and Society for Promotion of Engineering Education.

Membership • •

Recommended for Transfer

The board of examiners, at its meeting on February 20, 1941, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Affel, H. A., assistant director of transmission development, Bell Telephone Laboratories, Inc., New York, N. Y.
Black, H. S., member technical staff, Bell Telephone Laboratories, Inc., New York.
Bown, Ralph, director of radio and television research, Bell Telephone Laboratories, Inc., New York.
Dodd, R. L., assistant superintendent of electrical construction, Wisconsin Electric Power Company, Milwaukee, Wis.
Friis, H. T., radio research engineer, Bell Telephone Laboratories, Inc., Red Bank, N. J.
Mathes, R. C., associate director of circuit research, Bell Telephone Laboratories, Inc., New York.
Quarles, D. A., director of transmission development, Bell Telephone Laboratories, Inc., New York.
Strieby, M. E., engineer of transmission, American Telephone and Telegraph Company, New York.

8 to Grade of Fellow

To Grade of Member

Benedict, R. R., assistant professor of electrical engineering, University of Wisconsin, Madison, Wis.
Evans, W. H., electrical engineer, Sacramento Northern Railway, San Francisco, Calif.
Gray, L. A., electrical test engineer, Simplex Wire and Cable Company, Cambridge, Mass.
Grimes, C. O., lieutenant commander, United States Navy, Bureau of Ships, Washington, D. C.
Hoffman, K. B., assistant engineer, Consolidated Edison Company of New York, Inc., New York.
Lindemuth, H. F., assistant engineer, Consolidated Edison Company of New York, Inc., New York.
Redding, C. S., president, Leeds and Northrup Company, Philadelphia, Pa.
Rogers, F. H., assistant superintendent, meter and installation department, Consolidated Gas Electric Light and Power Company, Baltimore, Md.
Satterlee, W. W., division engineer, Westinghouse Electric and Manufacturing Company, Sharon, Pa.

9 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical Districts. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before March 31, 1941, or May 31, 1941 if the applicant resides outside of the United States or Canada.

United States and Canada

1. NORTH EASTERN

Abbott, C. T., Cambridge Electric Light Company, Cambridge, Mass.
Anderson, J. P., General Electric Company, Schenectady, N. Y.
Autuori, V. A., Southern New England Telephone Company, Bridgeport, Conn.
Bangs, W. A., Central New York Power Corporation, Syracuse, N. Y.
Beebe, M. F., United Illuminating Company, New Haven, Conn.
Black, T. L., General Electric Company, Pittsfield, Mass.
Boyles, R. L., General Electric Company, Schenectady, N. Y.
Brown, J. J. W., General Electric Company, Schenectady, N. Y.
Buckley, J. J., General Electric Company, Schenectady, N. Y.
Busch, F. H., General Electric Company, Lynn, Mass.
Butcher, R. O., General Electric Company, Lynn, Mass.
Byrnes, L. M., Central New York Power Corporation, Syracuse, N. Y.

Byron, K. D., General Electric Company, Schenectady, N. Y.
Casada, A. H., General Electric Company, Schenectady, N. Y.
Denby, H. H., Colonial Radio Corporation, Buffalo, N. Y.
Doddamuniswamappa, N., General Electric Company, Schenectady, N. Y.
Doozy, G. A., General Electric Company, Schenectady, N. Y.
Easton, I. G., General Radio Company, Cambridge, Mass.
Evans, H. R. (Member), General Electric Company, Pittsfield, Mass.
Fernald, A. E., General Electric Company, Lynn, Mass.
Fischer, E. E., Holtzer-Cabot Electric Company, Roxbury, Mass.
Floring, C. W., Central New York Power Company, Syracuse, N. Y.
Gettys, B., General Electric Company, Pittsfield, Mass.
German, R. E., General Electric Company, Lynn, Mass.
Greenleaf, N. P., Central New York Power Corporation, Syracuse, N. Y.
Guilloos, L. J., War Department, Rochester Ordnance District, Rochester, N. Y.
Hammond, R. L., General Electric Company, Schenectady, N. Y.
Harvey, A. L., United States Army, Plattsburg Barracks, N. Y.
Helin, C. J., Bagley and Sewall Company, Watertown, N. Y.
Hoffman, C. H., Massachusetts Institute of Technology, Cambridge, Mass.
Howland, H. W., General Electric Company, Pittsfield, Mass.
Hubbard, F. A., New Bedford Gas and Edison Light Company, New Bedford, Mass.
James, G. E., General Electric Company, Schenectady, N. Y.
Kalb, H. W., General Electric Company, Pittsfield, Mass.
Keen, R. N., General Electric Company, Pittsfield, Mass.
Kehoe, E. A., General Motors Corporation, Rochester N. Y.
Kelley, H. E., General Electric Company, West Lynn, Mass.
Kelly, P. E., Central New York Power Corporation, Syracuse, N. Y.
Kenney, H. M., General Electric Company, Lynn, Mass.
Knight, C. R., General Electric Company, Schenectady, N. Y.
Koon, K. S., International Business Machine Corporation, Endicott, N. Y.
Korneks, J. V., Jr., General Electric Company, Schenectady, N. Y.
Krause, L. O., General Electric Company, Schenectady, N. Y.
Kunz, L. C., Jr., General Electric Company, Schenectady, N. Y.
Lang, R. R., General Electric Company, Schenectady, N. Y.
Laue, F. G., General Electric Company, Schenectady, N. Y.
Lavoo, N. T., General Electric Company, Schenectady, N. Y.
Leitske, V. A., General Electric Company, Pittsfield, Mass.
Lister, C. A., General Electric Company, Schenectady, N. J.
Lommen, M. A. K., General Electric Company, Schenectady, N. Y.
MacEwan, A. Jr., Lynn Gas and Electric Company, Lynn, Mass.
Madsen, J. R., General Electric Company, Schenectady, N. Y. (for mail: 88 Monroe Place, Bloomfield, N. J.).
Maleck, J. C., General Electric Company, Schenectady, N. Y.
Manoogian, H., Pacific Mills, Lawrence, Mass.
Martin, D. W., General Electric Company, Schenectady, N. Y.
Martinez, S., Jr., General Electric Company, Schenectady, N. Y.
Mason, H. J., General Electric Company, Pittsfield, Mass.
Mathisen, M. E., General Electric Company, Schenectady, N. Y.
McGovern, A. D., United Illuminating Company, Bridgeport, Conn.
McMillan, F. R., General Electric Company, Schenectady, N. Y.
Mellion, H. H., Central New York Power Corporation, Syracuse, N. Y.
Morse, F. A., Jackson and Moreland, Boston, Mass.
Mulhern, M. J., Central New York Power Corporation, Potsdam, N. Y.
Nelson, R. A., General Electric Company, Pittsfield, Mass. (for mail: 210 E. Forrest Hill, Peoria, Ill.).
Olney, F. D., Jr., General Electric Company, Schenectady, N. Y.
O'Neill, P. F., Central New York Power Corporation, Syracuse, N. Y.
Parent, R. R., General Electric Company, Schenectady, N. Y. (for mail: High Falls, Crivitz, Wis.).
Pearson, D. B., General Electric Company, Schenectady, N. Y. (for mail: New Sweden, Maine).
Pearson, F. A., Central New York Power Corporation, Syracuse, N. Y.
Peck, D. S., General Electric Company, Schenectady, N. Y.
Philbin, T. R., Jr., Connecticut Light and Power Company, Essex, Conn.
Popp, J. M., General Electric Company, Schenectady, N. Y.
Poulsen, G. G., General Electric Company, Pittsfield, Mass.
Prechter, R. R., General Electric Company, Pittsfield, Mass.
Quayle, W., United States Navy, Buffalo, N. Y.
Redmond, J. J., General Electric Company, Lynn, Mass.
Reitz, H. N., Jr., Hamilton Standard Propellers, East Hartford, Conn.
Rhodes, E. K., Central New York Power Corporation, Syracuse, N. Y.
Rice, E. K., Westinghouse Electric and Manufacturing Company, Buffalo, N. Y.
Ridgway, W., General Electric Company, Schenectady, N. Y.
Rives, F. M. (Member), General Electric Company, Schenectady, N. Y.
Robinson, A. W., General Electric Company, Schenectady, N. Y.
Rohloff, H. E., Southern New England Telephone Company, New Haven, Conn.
Rosenkrans, F. A., General Electric Company, Lynn, Mass.
Rowe, S. H., General Electric Company, Schenectady, N. Y.
Schmitt, D. J., General Electric Company, Schenectady, N. Y.
Sherman, K. L., Central New York Power Corporation, Syracuse, N. Y.
Smith, E. P., American Steel and Wire Company, Worcester, Mass.
Solberg, W. O., General Electric Company, Pittsfield, Mass.
Stawicki, S. W., Champion Radio Works, Danvers, Mass.
Suits, C. G. (Member), General Electric Company, Schenectady, N. Y.
Taylor, J. A., Jr., General Electric Company, Schenectady, N. Y.
Thompson, G., General Electric Company, Schenectady, N. Y.
Toman, W. J. V., Colonial Radio Corporation, Buffalo, N. Y.
Townsend, C. W., Central New York Power Corporation, Syracuse, N. Y.
Tracy, J. F., General Electric Company, Schenectady, N. Y.
Turner, H. P., Westinghouse Electric and Manufacturing Company, Providence, R. I.
Vigour, H. E., General Electric Company, Schenectady, N. Y.
Wallace, D. E., General Electric Company, Schenectady, N. Y.
Warnock, W. J., General Electric Company, Schenectady, N. Y.
White, A., General Electric Company, West Lynn, Mass.
Whitehead, D. L., Cornell University, Ithaca, N. Y.
Wilkinson, J. W., General Electric Company, Pittsfield, Mass.
Williams, D. J. (Member), Central New York Power Corporation, Syracuse, N. Y.
Williams, G. R., Light and Power Department, Watertown, N. Y.
Woodward, L. J., Jr., General Electric Company, Schenectady, N. Y.

2. MIDDLE EASTERN

Abel, J. E., New York Shipbuilding Corporation, Camden, N. J.
Adams, E. F., Westinghouse Electric and Manufacturing Company, Wilkinsburg, Pa.
Adams, M. J., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Ankenbrandt, O. F., Ohio Bell Telephone Company, Cleveland, Ohio.
Aron, N., United States Navy, Baltimore, Md.
Ashley, G. W. (Member), Philco Corporation, Philadelphia, Pa.
Atkinson, J. F., Rural Electrification Administration, Washington, D. C.
Bailey, J. R., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Barth, G. R., Westinghouse Electric and Manufacturing Company, E. Pittsburgh, Pa.
Bedford, S. M., Jr., Chesapeake and Potomac Telephone Company of West Virginia, Clarksburg, W. Va.
Berry, H. C., Appalachian Electric Power Company, Cabin Creek, West Va.
Best, R. R., Ohio Bell Telephone Company, Cleveland, Ohio.
Bethea, W. H., Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Borgstadt, R. D., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Breland, C. O., Navy Department, Washington, D. C.
Brenner, W. C., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Brou, S., Naval Aircraft Factory, Philadelphia, Pa.
Brown, R. H., Union Switch and Signal Company, Swissvale, Pa.
Brown, W. C., General Electric Company, Erie, Pa.
Bubaltz, R. E., General Motors Corporation, Trenton, N. J. (for mail: 427 Louisa St., South Amboy, N. J.).
Buchholtz, H. C., United States Naval Academy, Annapolis, Maryland.
Buess, L. E., Chesapeake and Potomac Telephone Company of West Virginia, Charleston, W. Va.
Bungarda, C. A., American Telephone and Telegraph Company, Cleveland, O.
Byrum, J. F., Bethlehem Steel Company, Sparrows Point, Md.
Carbrey, R. L., Bell Telephone Laboratories, Incorporated, Baltimore, Md.
Cardwell, G. P., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Carpenter, C. E., General Electric Company, Philadelphia, Pa.
Cartwright, A. N. (Member), West Penn Power Company, Pittsburgh, Pa.
Case, S. R., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Chappuis, C. K., Putnam and Woolpert, Dayton, Ohio.
Chase, W. H. (Member), Ohio Bell Telephone Company, Cleveland, Ohio.
Clevenger, L. M., III, Sun Shipbuilding and Dry Dock Company, Chester, Pa.
Coleman, J. T., Jr., General Electric Company, Philadelphia, Pa.
Cooke, T. L., Jr., Austin Company, Cleveland, O.
Cooper, F. E., Westinghouse Electric and Manufacturing Company, Cleveland, Ohio.
Cooper, T. D., United States Government, Navy Department, Washington, D. C.
Cori, W. F., Jr., Philadelphia Electric Company, Philadelphia, Pa.
Cox, F., Metropolitan Edison Company, Easton, Pa.
Crane, L. R., Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa.
Dagan, I., General Motors Corporation, Dayton, O.
Daley, C. M., Jr., Philadelphia Electric Company, Philadelphia, Pa.
Dannettell, A. C., Yale & Towne Manufacturing Co., Philadelphia, Pa.
Davis, A., Jr., Westinghouse Electric and Manufacturing Company, Wilkinsburg, Pa. (for mail: Box 83, Johnson City, Texas).
Denton, R. H., Bureau of Ordnance, Navy Department, Washington, D. C.
Dingle, R. L., Taylor-Winfield Corporation, Warren, Ohio.
Dorsey, G. A., Westinghouse Electric and Manufacturing Company, E. Pittsburgh, Pa.
Drescher, L. L., Synchro-Start Products, Incorporated, Toledo, Ohio.
Edwards, R. F., Westinghouse Electric and Manufacturing Company, E. Pittsburgh, Pa.
Egeler, C. E. (Member), General Electric Company, Nela Park, Cleveland, O.
Erdmann, L., Philadelphia Electric Company, Philadelphia, Pa.
Erhard, R., Jr., The Jefferson Company, Smithfield, Ohio.
Fawcett, E. C., E. I. du Pont de Nemours and Company, Wilmington, Del.
Ferguson, S. J., Westinghouse Electric and Manufacturing Company, Wilkinsburg, Pa.
Finch, R. E., United States Government, Navy Department, Washington, D. C.
Ford, J. G., Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Foster, M. C., United States Army, Aberdeen Proving Ground, Md.
Frazee, H., Joy Manufacturing Company, Franklin, Pa.
Friedman, A. B., Allis-Chalmers Manufacturing Company, Pittsburgh, Pa.
Friedman, M. H., Bureau of Ordnance, Navy Department, Washington, D. C.
Frus, H. G., Westinghouse Electric and Manufacturing Company, E. Pittsburgh, Pa.
Fry, P. J., Westinghouse Electric and Manufacturing Company, E. Pittsburgh, Pa.
Gahm, W. L., United States Naval Aircraft Factory, Philadelphia, Pa.
Gaines, S., Jr., Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Gardiner, R. A., General Industries Company, Elyria, O.
Gilliam, A. A., Howard University Power Plant, Washington, D. C.
Golasky, F. W., Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Goldwag, H., Office of the Chief Signal Officer, War Department, Washington, D. C.
Goody, R. B., Gibson Electric Company, Pittsburgh, Pa.
Grasser, H. A., Toledo Edison Company, Toledo, Ohio.
Gund, R. A., General Electric Company, Philadelphia, Pa. (for mail: 4344 Wilcox Avenue, St. Louis, Mo.).
Hague, C. S., Jr., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Hemerich, H. A., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Helwig, F. C. (Member), Toledo Edison Company, Toledo, Ohio.
Herr, C. E., Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Hess, E. L., Bethlehem Steel Company, Bethlehem, Pa.
Honsinger, V. B., Ideal Electric and Manufacturing Company, Mansfield, O.
Hood, L. E., Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Hornstein, L., Babcock and Wilcox Company, Barberton, Ohio.
Housley, D. C., Rural Electrification Administration, Washington, D. C.
Jenkins, R. M., Duquesne Light Company, Pittsburgh, Pa.
Jennings, J., Westinghouse Electric and Manufacturing Company, E. Pittsburgh, Pa.
Jensen, H. E. (Member), Philco Corporation, Philadelphia, Pa.
Jones, I. K., American Telephone and Telegraph Company, Washington, D. C.
Kaiser, F. D., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Kaminski, J., Rural Electrification Administration, Washington, D. C.
Kasda, L. F., G. A. Gray Company, Cincinnati, Ohio.
Kempton, L. R., United States Army, Washington, D. C.
Kienzle, C. A., Philadelphia Electric Company, Philadelphia, Pa.
Kirsch, W. A., Carnegie Illinois Steel Corporation, Clairton, Pa.
Klein, L., Jr., Glenn L. Martin Company, Baltimore, Md.
Kosuchowski, W. J., Western Electric Company, Baltimore, Md.
Lash, J. C., The Cleveland Graphite Bronze Company, Cleveland, Ohio.
Lee, W. H., Electric Products Company, Cleveland, O.
Leemon, W., Ohio Bell Telephone Company, Cleveland, O.
Leise, M. S., Rural Electrification Administration, Washington, D. C.
Leithold, N. T., Adelphia Electric Company, Philadelphia, Pa.
Lloyd, K. H., Philadelphia Electric Company, Philadelphia, Penna.
Lyman, L. L., Austin Company, Cleveland, O.
Lynn, L. B., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Marshall, J. C., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Matthews, A. R., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. (for mail: 6 South Palouse Street, Walla Walla, Washington).
Mayorral, G. A., Crosley Radio Corporation, Station WLW, Cincinnati, O.
McClung, J. D., Koppers Coal Company, Fairview, W. Va.
McKee, C. G., Pennsylvania Power Company, New Castle, Pa.
Messmer, G. R., Rural Electrification Administration, Washington, D. C.
Michalowicz, J. C., Rural Electrification Administration, Washington, D. C.
Miller, D. M., Appalachian Electric Power Company, Huntington, W. Va.
Mitchell, F. T., Jr., Jansky and Bailey, Washington, D. C.
Myers, A. J., Jr., Rural Electrification Administration, Washington, D. C.
Norton, S. A., Federal Communications Commission, Washington, D. C.
Nurches, P., WADC Broadcasting Station, Akron, Ohio.
Oien, P. O., General Electric Company, Erie, Pa.
Olyarnik, E. N., Babcock and Wilcox Company, Barberton, O.
Osbon, W. O. (Member), Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Otis, S. J., Rural Electrification Administration, Washington, D. C.
Palmer, V. L., Civil Aeronautics Administration, Washington, D. C.
Parnell, J., Leeds and Northrup Company, Philadelphia, Pa.
Parton, C. A., Westinghouse Electric and Manufacturing Company, Lima, Ohio.
Pasco, T. G., Leece-Neville Company, Cleveland, Ohio.
Perkins, C. W., Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Pfaff, R. W. (Member), Philadelphia Electric Company, Philadelphia, Penna.
Pierce, J. D., Westinghouse Electric and Manufacturing Company, E. Pittsburgh, Pa.
Queen, S. D., Cleveland Electric Illuminating Company, Ashtabula, O.
Ramsay, W. L., New York Shipbuilding Corporation, Camden, N. J.
Rans, F. S., R. K. LeBlond Machine Tool Company, Cincinnati, O.
Ringe, G. T., Jr., Westinghouse Electric and Manufacturing Company, E. Pittsburgh, Pa.
Roach, D. D., Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa.
Rutledge, J. C., Leeds and Northrup Company, Philadelphia, Pa.
Sauer, L. B. (Member), Westinghouse Electric and Manufacturing Company, Sharon, Penna.
Scholz, W. R., Philadelphia Electric Company, Philadelphia, Pa.
Schroeder, D. J., Westinghouse Electric and Manufacturing Company, Sharon, Penna.
Schweder, W. M., 2nd Lieutenant, Ordnance Department, United States Army, Pedricktown, N. J.
Seeskin, P., Dayton Power and Light Company, Dayton, Ohio.
Sellers, A. H., Philadelphia Electric Company, Philadelphia, Pa.
Sen, W. J., Aircraft Radio Laboratory, War Department, Dayton, O.
Serrill, J. L., Jr., Leeds and Northrup Company, Philadelphia, Penna.
Shirland, F. A., Jr., National Carbon Company, Incorporated, Fostoria, O.
Shorter, O. L., Jr., General Electric Company, Philadelphia, Pa.
Shulman, J. M., Westinghouse Electric and Manufacturing Company, Lima, Ohio.
Siehr, V. P., Bell Telephone Company of Pennsylvania, Philadelphia, Pa.
Sizemore, C. (Member), District Pumping Station, Washington, D. C.
Skone, R. L., Westinghouse Electric and Manufacturing Company, E. Pittsburgh, Pa.
Sneed, A. B., Appalachian Electric Power Company, Bluefield, W. Va.
Snyder, K. G., Bethlehem Steel Company, Steelton, Pa.
Soper, F. W., Cleveland Electric Illuminating Company, Cleveland, O.
Spandau, E. P., George Worthington Company, Cleveland, Ohio.
Squires, R. B., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Steffey, W. J., Duquesne Light Company, Pittsburgh, Pa.
Storrs, G. H., Glen L. Martin Company, Baltimore, Md.
Strasburg, A. C., War Department, Aberdeen, Md.
Summers, C. L., Westinghouse Electric and Manufacturing Company, Wilkinsburg, Pa.
Swarm, H. M., Civil Aeronautics Administration, Washington, D. C.
Talley, H. J. (Member), American Telephone and Telegraph Company, Philadelphia, Pa.
Terkanian, H., War Department, Signal Corps Equipment, Dayton, O.
Thomas, H. W., United States Army, Allentown, Penna.
Thurston, T. L., Rural Electrification Administration, Washington, D. C.
Vetter, J. A., Koppers Company, Pittsburgh, Pa.
Voss, R. I., Philadelphia Electric Company, Philadelphia, Pa.
Wadsworth, C. V., Electric Controller and Manufacturing Company, Cleveland, O.
Webb, Mrs. H. J., 1315 Everett Street, Wilkinsburg, Pa.
Webb, H. J., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Wheeler, E., Westinghouse Electric and Manufacturing Company, E. Pittsburgh, Pa.
White, J. L., Cincinnati Gas and Electric Company, Cincinnati, Ohio.
Williams, J. S., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Williamson, J. L., University of Pittsburgh, Pittsburgh, Pa.
Williams, S. L., Westinghouse Electric and Manufacturing Company, E. Pittsburgh, Pa.
Williscon, G. N., Navy Department, Washington, D. C.
Williston, C. A., Yoder Machine Company, Cleveland, O.
Young, R. A., Washington Institute of Technology, Washington, D. C.
Zimmerman, W. O., Jr., Duquesne Light Company, West Bridgewater, Pa.

3. New York City

Amend, A., Jr., General Time Instruments Corporation, New York, N. Y.
Auditore, C. J., International Business Machines Corporation, New York, N. Y.
Berglund, P. T., Eclipse Aviation Corporation, East Orange, N. J.
Bulloch, E. (Member), New Jersey Bell Telephone Company, Newark, N. J.
Carlin, H. J., Westinghouse Electric and Manufacturing Company, Newark, N. J.
Carlson, C. S., White Dental Manufacturing Company, Staten Island, N. Y.
Chirles, A. M., Airlines Terminal, New York, N. Y.
Coppola, R. J., General Instrument Corporation, Elizabeth, N. J.
Deamant, H., Board of Transportation, New York, N. Y.
DeMott, E. G., Weston Electrical Instrument Corporation, Newark, N. J.
Dingeldein, J., United States Government, Navy Department, c/o Supervisor of Shipbuilding, New York, N. Y.
Dombrooki, S. J., Westinghouse Electric and Manufacturing Company, Newark, N. J.
Emmons, H. L., Jr., Jamesburg, N. J.
Frank, H. C. (Member), General Cable Corporation, Bayonne, N. J.
Garbarini, R. F., Empire Electric Brake Company, Newark, N. J.
Gessert, E. C., Jr., American Telephone and Telegraph Company, New York, N. Y.
Hagopian, W., War Department, New York Signal Corps, Procurement District, Brooklyn, N. Y.
Harrington, A. W., Jr., United States Army, Fort Monmouth, N. J.
Hauck, O. A., Grumman Aircraft Company, Bethpage, L. I., N. Y.
Hendrickson, J. G., War Department, New York Signal Corps, Procurement District, Brooklyn, N. Y.
Higgins, L. J. P., New York City Department Water Supply Gas and Electric, New York, N. Y.
Hough, R. R., Bell Telephone Laboratories, Incorporated, New York, N. Y.
Ketiladze, G. S., 480 Lexington Avenue, New York, N. Y.
Klein, M., Stevens Institute of Technology, Hoboken, N. J.
Kohler, G. M., Jr., Curtiss Wright Corporation, Caldwell, N. J.
Koppelon, R., 92 Passar Avenue, Newark, N. J.
Kunz, P. (Member), H. O. Boehme Incorporated, New York, N. Y.
Lund, H. A. (Member), New York Telephone Company, New York, N. Y.
Lurch, E. N., International Telephone and Telegraph Corporation, International Standard Electric Corporation, New York, N. Y.
Madill, J. T., Rbueco Services Inc., New York, N. Y.
Markosian, V., General Electric Company, Newark, N. J.
McCalip, C. E., Jr., Consolidated Edison Company of New York, Incorporated, New York, N. Y.
McCleece, H. M., Consolidated Edison Company of New York City, Inc., New York, N. Y.
Meyer, H. O., Federal Shipyard and Dry Dock Company, Kearny, N. J.
Milarta, L. E., Bell Telephone Laboratories Incorporated, New York, N. Y.
Miller, K. W., United States Army, Signal Corps, Fort Monmouth, N. J.
Miller, T. S., Jr., New York Telephone Company, New York, N. Y.
Mills, J. K., United States Army, Ordnance Department, Raritan Arsenal, Metuchen, N. J.
Moore, J. B. (Member), R.C.A. Communications, Inc., Riverhead, L. I., N. Y.
Morrison, J. F. (Member), Bell Telephone Laboratories, Incorporated, Whippany, N. J.
Nicolosi, J. P., Wright Aeroplane Corporation, Paterson, N. J.
Orlowski, W. F., American Transformer Company, Newark, N. J.
Overman, F. B., Jr., Underwriters' Laboratories, Incorporated, New York, N. Y.
Perini, F. A., Ward Leonard Electric Company, Mt. Vernon, N. Y.
Piatt, W. M., III, Rutgers University, New Brunswick, N. J.
Potter, J. L., Rutgers University, New Brunswick, N. J.
Pulhamus, W. R., Federal Shipbuilding and Drydock Company, Kearny, N. J.
Richardson, P. H., Bell Telephone Laboratories, Incorporated, New York, N. Y.
Rissberger, J. G., Bureau of Ships, United States Navy Department, New York, N. Y.
Rounds, P. W., Bell Telephone Laboratories Incorporated, New York, N. Y.
Sayre, J. E., Newark College of Engineering, Newark, N. J.
Scharmann, R. F., National Union Radio Corporation, Newark, N. J. (for mail: 1 Kenwood St., Pittsfield, Mass.).
Sherwin, J. P., Curtiss-Wright Corporation, Caldwell, N. J.
Stailing, G. E., Phelps Dodge Corporation, Elizabeth, N. J.
Stammerjohn, L. W., Bell Telephone Laboratories, New York, N. Y.
Sturgeon, W. S., Consolidated Edison Company of New York, Incorporated, New York, N. Y.
Sumner, R. J., City of New York, Department of Public Works, New York, N. Y.
Tenzer, M., War Department, New York Signal Corps, Procurement District, Brooklyn, N. Y.
Vissers, W., Jr., Radiomarine Corporation of America, New York, N. Y.
Vitale, S. A., American Telephone and Telegraph Company, New York, N. Y.
Wendel, L. A., Diehl Manufacturing Company, Elizabethport, N. J.
Weng, H. C., Harmon Foundation, Incorporated, New York, N. Y.
Westover, T. A., Public Service Electric and Gas Company, Irvington, N. J.
Wolstenholme, W. E., United States Rubber Company, Passaic, N. J.
Wootton, J. C., New York Telephone Company, New York, N. Y.

4. Southern

Barden, J. F., Jr., Atlantic Coast Line Railroad Company, Rocky Mount, N. C.
Bateman, F. F., Southern Bell Telephone and Telegraph Company, Columbia, S. C.
Blackstock, R., United States Army Air Corps, Coral Gables, Fla. (for mail: 180 Seventh Avenue, Brooklyn, N. Y.).
Bonnette, I. T., Carter Oil Company, Winnfield, La.
Callison, R. L., United States Army Air Corps, Montgomery, Ala.
Cantrell, S. W., Memphis Light Gas and Water Division, Memphis, Tenn.
Cheek, J. H., Jr., Pantops Farm, Charlottesville, Va.
Cronvich, J. A., Tulane University, New Orleans, La.
Dale, H. L., United States Navy Department, Portsmouth, Va.
Evans, R. D., The Okonite Company, Atlanta, Ga.
Fisher, R. W. (Member), War Department, U. S. Engineer Office, Brookley Field, Mobile, Ala.
Fletcher, R. A., U. S. Navy Department, Portsmouth, Va.
Fletcher, S. H., Virginia Public Service Company, Harrisonburg, Va.
Gore, J. P., Duke Power Company, Greenville, S. C.
Hall, C. N., United States Army, Fort Knox, Kentucky.
Hodges, R. C. (Member), Virginia Public Service Company, Arlington, Va.
Huff, V. N., National Advisory Committee for Aeronautics, Langley Field, Va.
Kelsall, A. C., Louisville Gas and Electric Company, Louisville, Ky.
Librizzi, P. N., United States Army, Fort Benning, Ga.
Manning, L. W., Nantahala Power and Light Company, Franklin, N. C.
Moncure, M. W. (Member), Public Works Office, Quantico, Va.
Muller, H. L., Maritime Electric Company, Incorporated, New Orleans, La.
Nelson, B. E., United States Army, Fort Jackson, S. C.
Nussbaum, C. W., D. T. Odom Electric Company, New Orleans, La.
Powell, L., Jr., Virginia Public Service Company, Clifton Forge, Va.

Rose, C. G., Joseph E. Seagram and Sons Company, Incorporated, Louisville, Ky.
Russell, J. D., Jr., Ken-Rad Tube and Lamp Company, Owensboro, Ky.
Sandidge, W. L., Virginia Public Service Company, Clifton Forge, Va.
Siler, H. K., Robert and Company, Jacksonville, Fla.
Skoog, R. K., National Advisory Committee for Aeronautics, Langley Field, Va.
Spahn, W. M., Jr., Tennessee Powder Company, Millington, Tenn.
Wilson, J. L., Jr., Southern Bell Telephone and Telegraph Co., Atlanta, Ga.

5. GREAT LAKES

Altman, N. P., Holabird and Root, Chicago, Ill.
Appleyard, R. E., Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Ayres, M. F., Louis Allis Company, Milwaukee, Wisconsin.
Beachum, J. H., Jr., Monsanto Chemical Company, Monsanto, Ill.
Beem, F. A., Illinois Bell Telephone Company, Springfield, Ill.
Berry, J. H., Public Utility Engineering and Service Corporation, Chicago, Ill.
Bloodworth, T. H., Allis-Chalmers Manufacturing Company, West Allis, Wis.
Boncyk, C. J., Interstate Power Company, Dubuque, Iowa.
Boyer, K. E., Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Byrne, C. J., Jr., Jefferson Electric Company, Bellwood, Illinois.
Camras, M., Armour Research Foundation, Chicago, Ill.
Cline, E. W., Commonwealth Edison Company, Chicago, Ill.
Connelly, J. B., Minerallac Electric Company, Chicago, Ill.
Cooper, J. K., Square D Company, Detroit, Mich.
Danforth, N. L., Jr., Allis-Chalmers Manufacturing Company, West Allis, Wis.
Daniels, L. H., General Motors Corporation, Grand Rapids, Mich.
Dicke, B. C., Firm of J. S. Hartt, Madison, Wis.
DiVito, N. J., Continental Steel Corporation, Kokomo, Ind.
Dupuis, H. F., Commonwealth and Southern Corporation, Jackson, Mich.
Elbourn, R. D., C. G. Conn, Ltd., Elkhart, Ind.
Ellison, N. D., Jr., Detroit Public Lighting Commission, Detroit, Mich.
Farr, W. H., Stewart Warner Corporation, Chicago, Ill.
Ferraro, G. E., Don C. Campion Laboratories, Detroit, Mich.
Fisher, F. H., Delco Remy Corporation, Anderson, Ind.
Fluehr, O. R., Kuhlman Electric Company, Bay City, Mich.
Foute, H. K., Drake Manufacturing Company, Chicago, Ill.
Harolds, O. S., Commonwealth Edison Company, Chicago, Ill.
Hayhurst, T. E., Fairbanks Morse Company, Beloit, Wis.
Heffelfinger, J. B., Collins Radio Company, Cedar Rapids, Iowa.
Herdman, D. F., Commonwealth Edison Company, Chicago, Ill.
Hilt, W. M., Westinghouse Electric and Manufacturing Company, Chicago, Ill.
Himelmayr, F. A., Bendix Aviation Corporation, South Bend, Ind.
Horn, E. H., Carnegie-Illinois Steel Corporation, Gary, Ind.
Howe, N. H., Dow Chemical Company, Midland, Michigan.
Humm, D. L., Illinois Testing Laboratories, Incorporated, Chicago, Ill.
Jackson, C. H., Purdue University, W. Lafayette, Ind.
Johnson, H. J. (Member), Commonwealth Edison Company, Chicago, Ill.
Johnson, J. E., Interstate Power Company, Dubuque, Iowa (for mail: 810 N. Main Street, Harrisburg, Ill.).
Johnson, J., Bryant Paper Company, Kalamazoo, Michigan.
Kennel, B. W., Russel Electric Company, Chicago, Ill.
Kotila, O. W. (Member), Copper District Power Company, Ontonagon, Mich.
LaHue, F. M., Brunswick, Balke, Collender Company, Muskegon, Mich.
Logan, J. R., Jr., Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
March, N. E., Chrysler Institute, Highland Park, Michigan.
Maury, T. F., Western United Gas and Electric Company, Aurora, Illinois.
Menard, E. O., Allis-Chalmers Company, West Allis, Wis.
Miller, J. (Member), Commonwealth and Southern Corporation, Jackson, Mich.
Moody, R. H., Westinghouse Electric and Manufacturing Company, Chicago, Ill.
Moore, R. B., Fairbanks-Morse and Company, Chicago, Ill.
Myron, G. M., Michigan Bell Telephone Company, Port Huron, Mich.
Nelson, R. F., Michigan State College, East Lansing, Mich.
Painter, R. O., General Motors Proving Ground, Milford, Michigan.
Peck, D. F., Barber-Colman Company, Rockford, Ill.
Pogorzelski, R., Wayne University, Detroit, Michigan.
Qualls, W. F., II, Grand Rapids Stamping Division, General Motors, Grand Rapids, Mich.
Rann, R. H., Electromotive Corporation, La Grange, Ill.
Rice, R. R., Minneapolis Honeywell Regulator Company, Minneapolis, Minn.
Rich, F. W., Commonwealth and Southern Corporation, Jackson, Mich.
Richards, W. E., Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Robbins, R. D., Indiana Associated Telephone Corporation, Lafayette, Indiana.
Russell, H. R., Diamond Chain and Manufacturing Company, Indianapolis, Ind.
Sarbacher, R. I. (Member), Illinois Institute of Technology, Chicago, Ill.
Schwarz-Kast, E. L., Armour Research Foundation, Chicago, Ill.
Schweitzer, E. O., Jr., War Department, United States Signal Section, Northbrook, Ill.
Scott, F. M., Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Shirkey, P. C., Jr., Inland Steel Company, Indiana Harbor, Ind.
Slayhi, E. L., Kellogg Company, Battle Creek, Michigan.
Smith, W. L., Commonwealth Edison Company, Chicago, Ill.
Spreuer, W. E., Shipshewana, Indiana.
Sturgis, C. C., Commonwealth Edison Company, Chicago, Ill.
Tones, T. E., General Motors Corporation, Detroit, Michigan.
Triplett, P., Allis-Chalmers Manufacturing Company, West Allis, Wis.
Veras, A. F., Commonwealth Edison Company, Chicago, Ill.

6. NORTH CENTRAL

Abbott, J. G. (Member), Mech Lectric, Omaha, Nebr.
Alexander, J. W., Rawlins Electric Company, Rawlins, Wyoming.
Cox, E. H., Westinghouse Electric and Manufacturing Company, Denver, Colo.
Miller, N. H., Miller Electric Company, Omaha, Nebr.
Rice, F. J., Electric Products Company, Minot, N. Dak.
Schwalb, W. R., University of Denver, Denver, Colorado.
Stauffer, L. M. (Member), General Electric Company, Denver, Colo.

7. SOUTH WEST

Alexander, K. B., Sheffield Steel Corporation, Kansas City, Mo.
Althaus, R. J., Emerson Electric Manufacturing Company, St. Louis, Mo.
Brands, J. T., Texas Power and Light Company, McKinney, Texas.
Doll, H. (Member), Schlumberger Well Surveying Corporation, Houston, Texas.
Elder, F. L., Arkansas-Missouri Power Corporation, Blytheville, Ark.
Farrington, W. H., Texas Electric Service Company, Fort Worth, Texas.
Gibson, G. B., H. B. Gieb and Company, Dallas, Texas.
Goodson, B. F., Texas Power and Light Company, Waco, Texas.
Hammond, L. R., Jr., Phelps Dodge Refining Corporation, El Paso, Texas.
Hollingsworth, W. R., Westinghouse Electric and Manufacturing Company, Houston, Texas.
Hunter, C. E., American Telephone and Telegraph Company, Wichita, Kansas.
Jabionsky, R. D., Union Electric Company of Missouri, St. Louis, Mo.
Johnson, L. E., New Mexico State College, State College, New Mexico.
Jones, R. H., Jr., Moloney Electric Company, St. Louis, Mo.
Jones, T. L., Southwestern Bell Telephone Company, St. Louis, Mo.
Koch, A. R., Jr., Bussmann Manufacturing Company, St. Louis, Mo.
Michael, R. R., Social Security Board, United States Government, Dallas, Texas.
Nesbett, P. S., Texas Power and Light Company, Dallas, Texas.
Neubauer, W. H., Petty Geophysical Engineering Company, San Antonio, Texas.
Schneider, F. T., Jr., United States Army, Fort Bliley, Kansas.
Smith, E. M., Bureau of Bridges, Jefferson City, Mo.
Sullivan, R. L., Transcontinental and Western Air, Incorporated, Kansas City, Mo.
Townsend, C. C., United States Army, Fort Sill, Okla.
Westin, C. L. (Member), Westinghouse Electric and Manufacturing Company, St. Louis, Mo.
Williams, J., Brown and Bellows, Corpus Christi, Texas.
Wray, H. H., Dallas Power and Light Company, Dallas, Texas.
Wright, S. C., Southwestern Bell Telephone Company, Tulsa, Okla.

8. PACIFIC

Carpenter, C. A., Lockheed Aircraft Corporation, Burbank, Calif.
Correy, T. B., Square D Company, Los Angeles, Calif.
Crispell, H. L., Commercial Radio Equipment Company, Hollywood, Calif.
Donovan, H. W., Lockheed Aircraft Corporation, Burbank, Calif.
Hansen, H. M., United States Army, Fort Ord, California.
Held, H. R., Weston Electrical Instrument Corporation, San Francisco, Calif.
Hosg, L. J., Standard Oil Company of California, Richmond, Calif.
Jahn, E. E., Pacific Gas and Electric Company, San Jose, Calif.
Kohler, F. L., United States Army, Monterey, Calif.
Lowe, J. W., Consolidated Aircraft Corporation, San Diego, Calif.
Morton, J. T., Jr., Holmes and Narver, Los Angeles, Calif.
Sandiford, P. L., Jr., Lockheed Aircraft Corporation, Burbank, Calif.
Scheiber, E. J., Mare Island Navy Yard, Vallejo, Calif.
Tudhope, G. V., Jr., City of Oakland, Calif.
Voitoff, G. E., Jacuzzi Brothers, Incorporated, Berkeley, Calif.
Wall, R. A., Southern California Telephone Company, Los Angeles, Calif.
Waters, C. H., San Francisco-Oakland Bay Bridge, Oakland, Calif.

9. NORTH WEST

Baldwin, F. S., Jobbus Supply Company, Seattle, Wash.
Beck, M. O., Puget Sound Power and Light Company, Olympia, Wash.
Bianchi, R., Montana School of Mines, Butte, Mont.
Davis, B., Deadwood Mine, Cascade, Idaho.
Donaldson, N. E., 1135 West Platinum, Butte.
Eggers, C. C., c/o Construction Quartermaster, Fort Lewis, Wash.
Finlayson, A., United States Navy, Bremerton, Washington.
Hahn, C. C., Boeing Aircraft Company, Seattle, Wash.
Hale, M. S., Puget Sound Power and Light Company, Bremerton, Washington.
Hall, G. J., Idaho Power Company, Boise, Idaho.
Hurlbut, H. C., United States Navy, Seattle, Wash.
Jeffs, T. W., United States Navy, Bremerton, Washington.
Kassens, A. H., Washington Water Power Company, Spokane, Washington.
Lamb, J. H., Cache Valley Electric Company, Logan, Utah.
Loveland, R. J., West Coast Telephone Company, Everett, Wash.
Randall, H. M., Radio Station KVI, Vashon Island, Wash.
Richardson, G. G., Idaho Power Company, Twin Falls, Idaho.
Sabo, J. J., The Montana Power Company, Great Falls, Montana.
Schneider, L. W., Washington Water Power Company, Spokane, Washington
Sedam, C. H., Puget Sound Power and Light Company, Seattle, Wash.
Swain, C. W., Boeing Aircraft Company, Seattle, Washington.
Thomson, A., Bonneville Power Administration, Portland, Oregon.
Walker, E., Route 2, Box 68, Beaverton, Ore.
Wiltala, M. F., United States Navy, Bremerton, Wash.

10. CANADA

Cosar, J., Canadian Westinghouse Company, Limited, Hamilton, Ont.
Hart, L. K., Canadian General Electric Company Limited, Toronto, Ont.
Jeckell, W. H. R., Canadian National Carbon Company, Limited, Toronto, Ont.
Martin, I. W. M., National Research Council, Ottawa.
Meyer, W. H., Canadian General Electric Company, Toronto, Ont.
Pegler, W. A., Canadian General Electric Company, Limited, Peterboro, Ont.
Pogson, J. R., British Columbia Electric Railway Company, Limited, Victoria, B. C.
Polson, W. A., Defence Industries Limited, Nobel, Ontario.
Ratcliff, J. H. (Member), Canadian General Electric Company, Toronto, Ont.
Rosen, C. A., Fairchild Aircraft Limited, Longueuil, Quebec.
Salto, G., Box 491, Ocean Falls, B. C.
Webb, E. S., British Columbia Electric Railway Company, Limited, Vancouver, B. C.

Total, United States and Canada 533

Elsewhere

Alfaro, H., Jr., c/o Constructing Quartermaster, Albrook Field, Canal Zone.
Alvarado, A., Puerto Rico Housing Authority, San Juan, Puerto Rico.
Casanas, J. A., Jr., School of Tropical Medicine, San Juan, Puerto Rico.
de Quevedo, J. L. G., University of Puerto Rico, Mayaguez, Puerto Rico.
Lugo, E. D., Puerto Rico Advertising Company, Mayaguez, P. R.
Romero, M. O., Centro Superior Tecnologico, Habana, Cuba.

Total, elsewhere, 6

Of Current Interest

Television Standards Submitted to FCC; Hearing to Be Held March 20

THE National Television System Committee, at a conference on January 27, 1941, submitted to the Federal Communications Commission 22 proposed standards for commercial operation of television. Following the conference the FCC announced that a formal public hearing on television would be held March 20, 1941, "for the purpose of considering the various engineering standards that have been suggested, and also to determine when television broadcasting should be placed on a commercial basis."

The committee was created during the summer of 1940 by the television industry in collaboration with the FCC, to seek solutions of the crucial technical problems of television. Its members are the following:

W. R. G. Baker (A'19) General Electric Company, *chairman;* Virgil M. Graham, Emporium, Pa., *secretary;* E. F. W. Alexanderson (F'20) General Electric Company; Ralph Bown (M'30) Bell Telephone Laboratories; B. Ray Cummings (A'18) Farnsworth Television and Radio Corporation; Allen B. DuMont, Allen B. DuMont Laboratories, Inc.; E. W. Engstrom, RCA Manufacturing Company, Inc.; A. N. Goldsmith (F'20) Institute of Radio Engineers; Daniel E. Harnett (M'38) Hazeltine Corporation; John V. L. Hogan (M'20) National Association of Broadcasters; John R. Howland, Zenith Radio Corporation; Albert I. Lodwick, Hughes Tool Company; R. H. Manson (M'18) Stromberg-Carlson Telephone Manufacturing Company; Adrian Murphy, Columbia Broadcasting System; Paul C. Raibourn, Television Productions; David B. Smith, Philco Corporation.

The full text of the committee's report to the FCC follows.

REPORT OF THE COMMITTEE

The National Television System Committee recommends herewith transmission standards for commercial television broadcasting. The committee recognizes the co-ordinate importance of standardization and the commercial application of technical developments now in the research laboratories. These standards will make possible the creation, in the public interest, of a nationally co-ordinated television service and at the same time will insure continued development of the art.

Monochromatic transmission systems other than those embodied in these standards should be permitted to operate commercially, when a substantial improvement would result, provided that the transmission system has been adequately field tested and that the system is adequately receivable on receivers responsive to the then existing standards.

This committee believes that, although color television is not at this time ready for commercial standardization, the potential importance of color to the television art requires that

(a). A full test of color on the Group A channels be permitted and encouraged, and that

(b). After successful field test, the early admission of color to the Group A channels on a commercial basis coexistent with monochromatic television be permitted, employing the same standards as are herewith submitted except as to lines and frame and field frequencies. The presently favored values for lines, frame and field frequencies for such a color system are, respectively, 343, 60, and 120.

Those transmission standards are recommended for commercial television broadcasting on the following channels:

Channel Number	Megacycles
1	50– 56
2	60– 66
3	66– 72
4	78– 84
5	84– 90
6	96–102
7	102–108

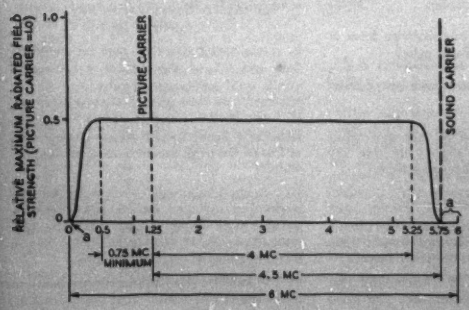

Figure 1. Idealized picture-transmission amplitude characteristic

(a)—Relative field strength of picture side band not to exceed 0.0005

Drawing not to scale

I: The Television Channel

1. The width of the standard television broadcast channel shall be 6 megacycles per second.

2. It shall be standard to locate the picture carrier 4.5 megacycles per second lower in frequency than the unmodulated sound carrier.

3. It shall be standard to locate the unmodulated sound carrier 0.25 megacycle per second lower than the upper frequency limit of the channel.

4. The standard picture transmission amplitude characteristic shall be that shown in figure 1.

II: Scanning Specifications

5. The standard number of scanning lines per frame period in monochrome shall be 441, interlaced two to one.

6. The standard frame frequency shall be 30 per second and the standard field frequency shall be 60 per second in monochrome.

7. The standard aspect ratio of the transmitted television picture shall be four units horizontally to three units vertically.

8. It shall be standard, during the active scanning intervals, to scan the scene from left to right horizontally and from top to bottom vertically, at uniform velocities.

III: Picture Signal Modulation

9. It shall be standard in television transmission to use amplitude modulation for both picture and synchronizing signals, the two signals occupying different amplitude ranges.

10. It shall be standard that a decrease in initial light intensity cause an increase in radiated power.

11. It shall be standard that the black level be represented by a definite carrier level, independent of light and shade in the picture.

12. It shall be standard to transmit the black level at 75 per cent (with a tolerance of plus or minus 2.5 per cent) of the peak carrier amplitude.

IV: Sound Signal Modulation

13. It shall be standard to use frequency modulation for the television sound transmission.

14. It shall be standard to pre-emphasize the sound transmission in accordance with the impedance-frequency characteristic of a series inductance-resistance network having a time constant of 100 microseconds.

V: Synchronizing Signals

15. It shall be standard in television transmission to radiate the synchronizing wave form shown in figure 2.

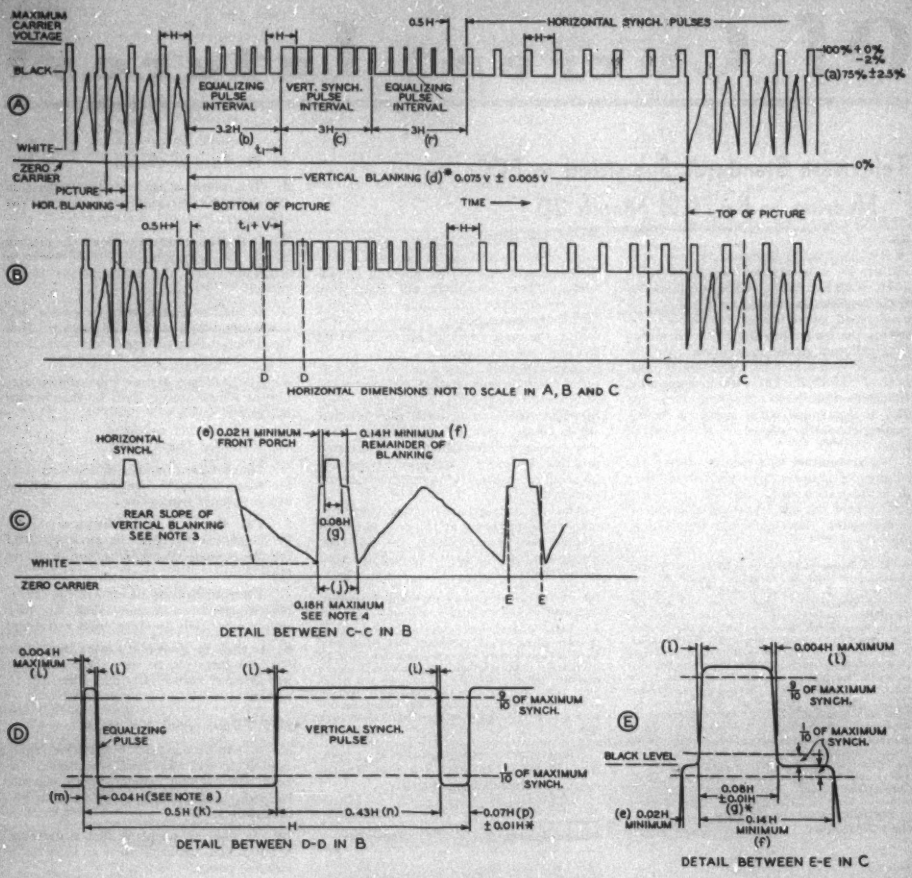

Figure 2. Television synchronizing wave form

1. H = time from start of one line to start of next line
2. V = time from start of one field to start of next field
3. Leading and trailing edges of vertical blanking should be complete in less than $0.1H$
4. Leading and trailing slopes of horizontal blanking must be steep enough to preserve minimum and maximum values ($e+f$) and (h) under all conditions of picture content
5. There shall be no overshoot on front or rear slopes of any pulses
6. * Dimensions marked with an asterisk indicate that tolerances given are permitted only for long-time variations and not for successive cycles
7. For receiver design, vertical retrace shall be complete in $0.07V$
8. Equalizing pulse area shall be between 0.45 and 0.5 of the area of a horizontal synchronizing pulse

16. It shall be standard that the time interval between the leading edges of successive horizontal pulses shall vary less than 0.5 per cent of the average interval.

17. It shall be standard in television studio transmission that the rate of change of the frequency of recurrence of the leading edges of the horizontal synchronizing signals be not greater than 0.15 per cent per second, the frequency to be determined by an averaging process carried out over a period of not less than 20, nor more than 100, lines, such lines not to include any portion of the vertical blanking signal.*

VI: Transmitter Ratings

18. It shall be standard to rate the picture transmitter in terms of its peak power when transmitting a standard television signal.

19. It shall be standard in the modulation of the picture transmitter that the radio frequency signal amplitude be 15 per cent or less of the peak amplitude, for maximum white.†

20. It shall be standard to employ an unmodulated radiated carrier power of the sound transmission not less than 50 nor more than 100 per cent of the peak radiated power of the picture transmission.

21. It shall be standard in the modulation of the sound transmitter that the maximum

deviation shall be plus or minus 75 kilocycles per second.

VII: Polarization

22. It shall be standard in television broadcasting to radiate horizontally polarized waves.

* It is recommended that as progress in the art makes it desirable the maximum rate of change of frequency of the transmitted horizontal synchronizing signals for studio programs be reduced and that limits be set for transmissions originating elsewhere than in the studio.

† It is the opinion of the NTSC that a picture transmitter not capable of a drop in radio frequency signal amplitude to 15 per cent or less of the peak amplitude would be unsatisfactory since it would not utilize to the best advantage the available radio frequency power. At the same time the NTSC is aware of the practical situation that it may not be possible for all of the first picture transmitters to meet this standard. It should be possible in picture transmitters for the lower frequency channels in Group A to meet this standard, although it may not be possible for picture transmitters for the higher frequency channels in Group A to meet it at first. After the first operation on the higher frequency channels and as designs progress it should be possible to meet it. It is requested that the Federal Communications Commission take cognizance of this situation.

Other Societies •

Alfred Noble Prize Not Awarded for 1940

No award of the Alfred Noble Prize will be made for 1940, according to recent announcement by the Alfred Noble Prize committee. Normally the prize, which was established in 1929 in memory of the late Alfred Noble, is awarded annually by a joint committee representing the American Society of Civil Engineers, American Society of Mechanical Engineers, AIEE, American Institute of Mining and Metallurgical Engineers, and Western Society of Engineers, for a technical paper of exceptional merit, by an author under 31 years of age. C. E. Shannon (A'39), Massachusetts Institute of Technology, won the 1939 award.

In its recent announcement, the committee describes the character of the prize and the considerations governing its award, as follows:

"The award consists in a certificate, a cash prize, amount dependent on income, which is now $350, plus an allowance for the traveling expenses of the recipient to the annual meeting of the society of which he is a member and at which the award is made.

"The Alfred Noble Prize is normally awarded annually for 'a technical paper of exceptional merit' which has been published during the year ending May 31 by one of the participating societies, provided that the author has not passed his 31st birthday at the time the paper is submitted for publication 'in practically its final form.'

"The prize committee has always attempted to interpret the term 'technical' in a liberal manner. The awards have gone both to papers of a largely descriptive type and to papers of a highly mathematical nature. It is deemed essential, however, that any descriptive paper should contain a sufficient amount of factual data, analysis, and detail to make it of more definite value to the profession than a simple news report. Similarly, no paper of the mathematical type is considered satisfactory if it offers no promise of practical application. The award is for a technical rather than a scientific paper, and practical values are a *sine qua non*.

"Needless to say, the paper must be an individual work of the author, must reflect originality. Presumably any author will make suitable acknowledgment in his paper for aid or suggestions received from his colleagues or superiors, and all papers are naturally subject to the usual editorial changes of the publisher. A joint paper, or one which does not reflect individual effort and initiative, is not, however, acceptable.

"A paper must be of 'exceptional merit.' The committee recognizes that the younger members in our national societies—both the young engineers in practice and the young men undertaking postgraduate work in an engineering school—have made and are making valuable contributions to the technical progress of the engineering profession. It is natural, however, that many of these contributions will consist of minor improvements in the detail of existing practice or similar extensions of present theory or technique. The committee must judge when such contributions are sufficiently outstanding as to indicate 'exceptional merit.' This is, of course, a difficult question, and in answering it the Committee endeavors to secure the advice of senior engineers who are experienced in the special field covered by the paper in question.

"It is also the view of the Committee that the paper should be of a character suitable for presentation at a meeting or for publication in the permanent technical records of the society, that is, proceedings or transactions. If the Noble Prize is to be maintained on a high plane of competition, it is inevitable that the burden of proof as to importance and exceptional merit must rest with the paper. Accordingly the committee, while attempting to keep its standards reasonable, must insist that 'exceptional merit' be clearly demonstrated.

"Papers are not 'entered' for the Alfred Noble Prize. Each year a list of *all* papers which meet the requirements as to publication, authorship, etc., are studied by an appropriate group within each of the participating societies. The paper recommended by the representative of each society on the Alfred Noble Prize committee is then considered by the committee and of the papers so submitted one is selected by this committee for the award, or no award is made."

ASA Provides for Defense Emergency Standards

The American Standards Association, in order to be prepared to act promptly on requests for the preparation of standards for use in the national defense program has adopted a temporary annex to its "Procedure". This annex, approved January 7, 1941, greatly abbreviates the normal procedure applying to the development and approval of standards in ASA. The provisions of the annex follow:

(*a*). Defense emergency standards, developed or adopted under the following abbreviated procedure, may be issued by the Association under authority of the Standards Council.

(*b*). Any request for the development or adoption of such a standard shall be referred to the chairman of the Standards Council. If in his opinion such a standard is urgently needed in the interest of national defense, he shall so declare and shall notify the Standards Council to that effect.

(*c*). The chairman of the Council, together with the chairman of the appropriate correlating committee or committees, shall act for the Council on the approval of a project, the scope of the project, the method of procedure to be used, and where a project committee is necessary shall appoint its personnel.

(*d*). In the case of standards drafted by the emergency technical committees, the draft shall be referred to a reasonable number of key individuals in the groups having a substantial concern with the subject of the standard, with the request that their comments be returned within a limited period of time. The emergency technical committee shall consider all such comments, and in submitting the revised draft for action by the appropriate correlating committee shall report what disposition has been made of the comments.

(*e*). The chairman of the Council shall act for the Council on the approval of a standard as a defense emergency standard, upon favorable recommendation of the correlating committee concerned, or the board of examination, but a 1/6 negative vote of a correlating committee, or one negative vote of the board of examination, shall prevent the issuance of any such standard.

(*f*). The members of the Standards Council and of the correlating committee concerned, shall be informed promptly of all requests for standards, and of proposed scopes, methods of procedure to be used, personnel of committees, and submittals of standards for approval.

(*g*). All such defense emergency standards shall be published in a distinctive uniform format. The words Defense Emergency shall appear in the title, e.g.,

American Defense Emergency Standard
Specifications for.....

(*h*). After the emergency shall have passed, the defense emergency standards will be immediately reviewed by the appropriate correlating committees, and approved, amended, or withdrawn, through the regular procedures of the Association.

Future Meetings of Other Societies

American Chemical Society. April 7–11, 1941, St. Louis, Mo.

American Institute of Chemical Engineers. Semi-annual meeting, May 19–21, 1941, Chicago, Ill.

American Physical Society. 241st meeting, May 1–3, 1941, Washington, D. C.

American Railway Engineering Association. Annual meeting, March 11–13, 1941, Chicago, Ill.

American Society for Testing Materials. 44th annual meeting, June 23–27, 1941, Chicago, Ill.

American Society of Civil Engineers. Spring meeting, April 23–25, 1941, Baltimore, Md.

American Society of Mechanical Engineers. Spring meeting, March 31–April 3, 1941, Atlanta, Ga.
Semiannual meeting, June 16–20, 1941, Kansas City, Mo.

Edison Electric Institute. June 2–5, 1941, Buffalo, N. Y.

Electrochemical Society. Spring meeting, April 16–19, 1941, Cleveland, Ohio.

Illuminating Engineering Society. 2d annual lighting conference, April 25–26, 1941, San Francisco, Calif.

Midwest Power Conference. April 9–10, 1941, Chicago, Ill.

National Electrical Manufacturers Association. May 11–15, 1941, Hot Springs, Va.

Society of Automotive Engineers. National production meeting, May 12–13, 1941, Milwaukee, Wis.
Summer meeting, June 1–6, 1941, White Sulphur Springs, W. Va.

Letters to the Editor • • •

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

A Simple Method of Calculating Power Factor

To the Editor:

Mr. Graybeal's method of calculating power factor (*EE, Nov. '40, p. 480*) is correct and not too cumbersome, but he is not using his slide rule to the greatest advantage.

Practically every slide rule except the 25-cent rules—and an engineer who uses one of those ought to be ashamed of himself—has the sine and tangent scales. Why not put these scales to use?

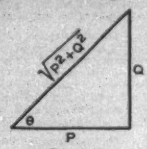

Figure 1

Consider the following analysis for determining power factor:

$$PF = \frac{P}{\sqrt{P^2+Q^2}} = \cos\theta$$

But

$$\theta = \tan^{-1} Q/P$$

Hence

$$PF = \cos(\tan^{-1} Q/P)$$

Therefore simply find the angle whose tangent is Q/P, and then find the cosine of that angle.

This method may not be shorter than Mr. Graybeal's but it certainly is no longer; it is more fundamental, and the decimal-point worry has been entirely eliminated.

SANFORD HERSHFIELD (Enrolled Student)

(Cooper Union Institute of Technology, New York, N. Y.)

A Simple Method of Calculating Power Factor

To the Editor:

In his letter on calculation of power factor (*EE, Nov. '40, p. 480*) Troy D. Graybeal has indicated a simple means of vector transformation on a small slide rule. However, because he did not specifically state this connection, and because as a student I know how many hours I have wasted in lengthy vector changes, I should like to draw attention to this very fast system. Perhaps I should mention that I first came across the method in *Civil Engineering*, December 1937. Although it seems general knowledge, no one has printed it for the benefit of us beginners.

Using the common rule with seven scales (*A, B, C, D*, and log, sin, tan on reverse of slide), the same procedure is followed in changing $a+jb$ to $A\angle\theta$ by using form

$$a+jb = \sqrt{a^2+b^2} \ \angle\tan^{-1} b/a$$

but in the first step the angle is read from the rear of the slide (taking care that the first fraction is of such magnitude that the correct angle is read, depending upon direction of the scales).

In going from $A\angle\theta$ to $a+jb (= A\cos\theta + jA\sin\theta)$, A is set on A scale and the slide is moved to first sin $(90°-\theta°)$ and later to sin $\theta°$. Thus $a+jb$ is found by reading a and b directly under the indicator on the B scale under A. The principle used is, of course, that $\cos\theta = \sin(90°-\theta°)$.

These simple operations may prove helpful to those using vectors frequently. In the hope of simplifying the solution for cube root on these rules, I offer the following hint:

First divide or multiply by 1,000, 1,000,000, etc., so as to place result in range 1–1,000. For numbers 1–10 and 100–1,000 use left half of A scale and for those of 10–100 use right half. Use only left half of B scale for all ranges, with restriction of 1 to 2.15 for numbers 1–10, 2.15 to 4.64 for 10–100, and 4.64 to 10 for 100–1,000.

Simply set indicator on number on A scale as above and move slide until number on B scale directly beneath hairline coincides with number under index, on D scale, which number then is the cube root, remembering correct decimal place. The actual operations take but a few seconds.

Because of the number of student readers, myself included, I should like to petition for a small nook among the "letters" devoted to hints of short cuts in using the slide rule. There may be many timesavers now potent only in the minds of some old-timers.

WILLIAM C. URLOVIC (Enrolled Student)

(Electric department, Pacific Gas and Electric Company, San Francisco, Calif.)

Books Received •

"Temperature—Its Measurement and Control in Science and Industry". To make permanently available the valuable papers presented at a symposium on this subject sponsored by the American Institute of Physics with the co-operation of the National Bureau of Standards and the National Research Council, held last winter in New York (*EE Oct. '39, p. 437*) they have been collected in a 1,375-page volume. Also co-operating in the project were: American Ceramic Society, American Chemical Society, American Institute of Mining and Metallurgical Engineers, American Society of Mechanical Engineers, American Society for Metals, American Society of Heating and Ventilating Engineers, American Society of Refrigerating Engineers, American Society for Testing Materials, American Standards Association, American Welding Society, Society of Automotive Engineers, and American Foundrymen's Association.

The original papers have been carefully edited by authorities in their fields. They have also been rearranged, supplemented, and exhaustively indexed. All phases of temperature are covered in great detail. The material in the book is arranged in 13 chapters headed as follows: temperature and temperature scales; precision thermometry; education; natural sciences; temperature in biology; temperature and its regulation in man; automatic temperature regulation and recording; special applications and methods; general engineering; metals and ceramic industries; oil industries; optical and radiation pyrometry; and thermometric metals and alloys.

The book is expected to be especially valuable for chemists, teachers, physicists, biologists, medical men, metallurgists, geologists, electrical, mechanical and refrigerating engineers, and plant operating officials. By special arrangement, the book is published by the Reinhold Publishing Corporation, 330 West 42nd Street, New York City, list price $11.00 per copy. An appendix of 25 reference tables is included, which also may be purchased separately bound for $1.00 per copy.

"Men and Volts". Subtitled "The Story of General Electric", "Men and Volts" by John Winthrop Hammond tells of the development of the electrical era, from 1876 to 1940, in particular relation to the growth of the General Electric Company. The history as written by Hammond ends with the year 1922; to bring the record up to date an epilogue has been added, and the statement made by Owen D. Young to the Temporary National Economic Committee in 1939 included as an appendix. Published by J. B. Lippincott Company, Philadelphia, 1941; 436 pages, illustrated; price $2.50.

The following new books are among those recently received at the engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

COMMISSIONING OF ELECTRICAL PLANT AND ASSOCIATED PROBLEMS (Monographs on Electrical Engineering, volume V). By R. C. H. Richardson. Chapman and Hall, London, 1938. 363 pages, diagrams, etc., 9 by 5½ inches, cloth, 24s. Aims to present general and specific information which has been found useful when putting into service both a-c and d-c generating, transforming, motive, and converting equipment. The preparation, likely troubles, and efficient testing of such equipment are fully described, and the last chapter outlines briefly several important conceptions useful in electrical-engineering calculations. There is a classified selected bibliography.

INDUSTRIAL MANAGEMENT. By R. H. Lansburgh and W. R. Spriegel. Third edition, John Wiley and Sons, New York, 1940. 666 pages, illustrated, 9 by 6 inches, cloth, $4.50. General organization technique is stressed in this discussion of the principles, problems, ideals, and successful methods of industrial management. In considering the plant, the product, personnel, wage payment, managerial controls, and operating procedures, an effort has been made to show the relationships of each major portion of a business to the others and to outside influences. Bibliography.

BILDWORT DEUTSCH TECHNISCHE SPRACHHEFTE 3. STARKSTROMTECHNIK. VDI-Verlag, Berlin, 1940. 36 pages, illustrated, 8½ by 6 inches, paper, 1.80 rm.; to members, 1.35 rm. Power-current technology is the subject of this third in a series of pamphlets designed to help engineers to read German technical publications. Various related topics are described and labeled, and illustrative diagrams are included as vocabulary aids. Large subject index.

Transactions Section

Preprint of Corresponding Pages From the Current Annual Transactions Volume

Any discussion of these papers will appear in the June 1941 "Supplement to Electrical Engineering—Transactions Section"

A Power-System Governor Sensitive to Frequency and Load

THOMAS E. CURTIS
ASSOCIATE AIEE

Synopsis: This paper describes a new electrical control system with which a standard power-system governor may be made sensitive to system load as well as frequency. A proposed scheme of application is presented which is believed to permit electrical control of a standard governor instead of mechanical control, without any sacrifice of reliability.

THE frequency of a power system is governed by controlling the power input to the prime movers of the system. Consider, for example, a typical power system in which one hydraulically-driven synchronous generator is governing the system frequency. Since the remaining generating units are operating at constant loads, the power output of the governing unit must be regulated so that the unit will assume any variations of load on the system. Simultaneously, this unit is controlled to hold the system frequency at a constant value.

Figure 1 is the schematic representation of a typical governing system of a hydro-electric generating unit. The power output of this unit is regulated by varying the opening of the needle valve to control the flow of water through the turbine This valve is operated by oil pressure through a control valve and piston, as shown in figure 2. The speed-sensitive element in this governing system is a centrifugal governor, driven from the turbine shaft, which operates the control valve by pivoting the beam about point P.

To meet changing system load, the load level of the governor is varied by the electrically-operated load control. The load control is operated through a contact-making frequency meter, connected to the system, which periodically resets the motor to change the relationship between the elevation of point P and the opening of the needle valve. The governor operation is thereby made isochronous.

It is now pointed out that the governing system just described is actuated by turbine speed and system frequency. A definite time lag must then exist in its operation to compensate for system load changes, since the rate of change of frequency which results from a differential between power generated and power demanded must exist for a definite period of time before frequency and turbine speed change sufficiently to actuate the governor. It is the purpose of this paper to describe a new governing system which is sensitive to both frequency and load.

Paper 41-15, recommended by the AIEE committee on power generation and presented at the AIEE winter convention, Philadelphia, Pa., January 27–31, 1941.

Manuscript submitted November 25, 1940; made available for preprinting November 28, 1940.

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Operating Principle

Figure 3 is a schematic representation of the proposed governing system. The turbine governor is actuated by an electronic frequency controller, through the medium of a balanced solenoid. This frequency controller provides two distinct components of control to make the governor sensitive to both frequency and load. The first component is derived from the pair of d-c currents I_A and I_B as functions of α, the rate of change of frequency in cycles per second per second. The second component is derived from the pair of d-c currents I_C and I_D as functions of F, the frequency in cycles per second. The controlling currents I_A, I_B, I_C, and I_D are obtained through the use of vacuum-tube circuits in the frequency controller. The characteristic operating curves are shown in figure 3. Current values are indicated in milliamperes. The solenoid plunger is then displaced from its central position in proportion to the current unbalance between I_A+I_C and I_B+I_D. An unbalance of I_A and I_B then actuates

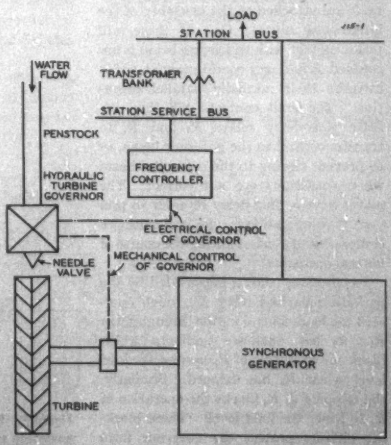

Figure 1. Governing schematic of hydroelectric generating unit

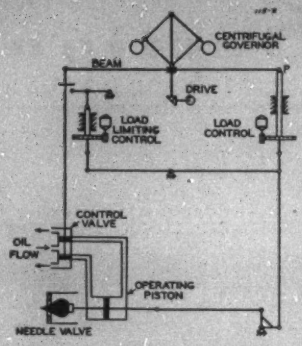

Figure 2. Hydraulic turbine governor schematic

the governor instantaneously whenever equilibrium is disturbed between power generated and power demanded. An unbalance of I_C and I_D actuates the governor whenever frequency deviates from its normal value.

The balanced solenoid operates the governor control valve through the conventional mechanical linkage, similar to that shown in figure 2. However, the standard centrifugal governor is retained on a separate beam. The controller beam and the governor beam have a common pivot at one end. At the other end, there is an interlocking pivot arrangement which couples to either one beam or the other. The solenoid M is energized to transfer *from* the governor beam *to* the controller beam. Signal lights S indicate which beam is in use. Four limit contacts are attached to the assembly of the interlocked pivots. One of these will make contact with whichever beam is uncoupled should any condition arise which disturbs their normally parallel operation. The limit contacts will then operate time-delay relays R_3 and R_4 to transfer control to the governor beam, or to prevent closing to the controller beam when conditions are not correct. The relays have a time delay in order to prevent their operation by the load-sensitive component of control during the course of normal operation.

Isochronous control is provided by the periodic polarized relay R_2, which operates the load-control motor through relay R_1. R_2 has auxiliary contacts which block the operation of R_1 to raise the load level when R_2 has tripped. Similarly, the tripping of R_4 blocks the operation of R_1 to lower the load level. These blocking circuits protect the governor from faulty operation of the load control. As indicated in figure 3, automatic time control may be coupled in at relay R_5.

Due to the use of balanced circuits throughout the frequency controller, it is possible to place a balance relay R_6 in the common-current return to terminal E. Any fault conditions within the controller will change the current in R_6, thereby tripping R_6 instantaneously to transfer control to the governor beam. By shorting out R_5, the tripping of R_6 also prevents possible erroneous operation of the load control. Control is automatically transferred to the controller beam when the current through R_6 returns to normal, provided that the transfer circuit has not been opened by either R_3 or R_4.

As outlined above, the control system is protected against faults within the controller by balance relay R_6. If, for any reason, R_6 should fail to operate, either R_3 or R_4 will transfer control to the governor beam. Relays R_3 and R_4 provide a continuous check of the calibration of the frequency controller against the centrifugal governor.

For the sake of simplicity, the load-limiting control is not indicated in figure 3. See figure 2.

The operation of the control system for a sudden increase of load is indicated in figure 4. The curve I_B-I_C represents frequency deviation, and curve I_B-I_A represents rate of change of frequency. The solenoid operation is represented by the sum of these two curves, $-I_A+I_B-I_C+I_D$. The shaded area A for time T represents the net improvement in control that this proposed control system provides over and above that of existing governing systems. The operation of the load-control motor is indicated at the bottom of the figure.

Solenoid Characteristics

In figure 5 are shown the operating characteristics of the balanced solenoid. The ordinates D represent the displacement of the plunger from its central position. The force-versus-displacement curves for each coil change with the frequency applied to the controller. Thus, for an applied frequency of 60.5 cycles per second, the force curves of the two coils intersect at P_5, whose ordinate is the displacement assumed by the plunger. When the frequency applied to the controller is 60 cycles, the force curves intersect at P_4, where the plunger displacement D is equal to zero.

If a differential force dF is applied to the plunger, it can move through a displacement D_2, as indicated. This differential force may represent either the threshold force of the valve linkage or a

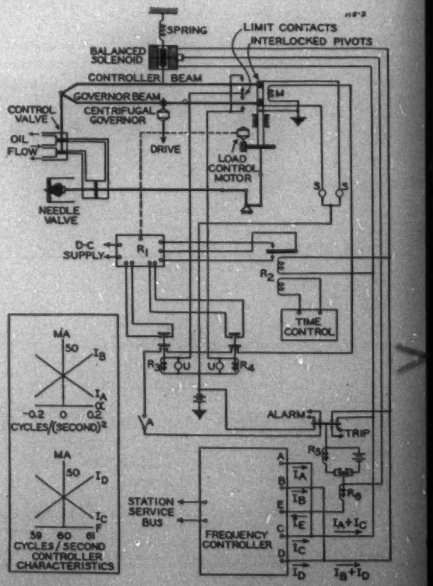

Figure 3. Proposed governing system

force tending to produce oscillation. In figure 6, which indicates the equilibrant forces of the centrifugal governor, it can be seen that the same differential force dF produces a relatively greater displacement D_1. Therefore, in comparing a centrifugal governor with a balanced solenoid operating in the same force range, the threshold limit of operation and the magnitude of possible oscillation of the solenoid is about one-half that of the former.

Curve A in figure 6 represents the restraining force of the centrifugal governor. The operating displacement is determined by its point of intersection with the lifting-force curve corresponding to the system frequency and turbine speed.

Controller Circuit

Figure 7 is the schematic circuit diagram of the frequency controller. System frequency is supplied to the controller through transformer T_1. A capacitance C_1 is connected in the circuit of one secondary winding, and an inductance L_1 is connected in the other. As frequency increases, the a-c current through R_1 decreases, while that through R_2 increases. The magnitudes of the a-c voltages appearing across R_1 and R_2 are converted into correspondingly proportional d-c currents in R_9 and R_{10}. This conversion is accomplished by vacuum tubes V_1, V_2, V_3, V_4, V_5, V_6, V_7, and V_8. Phase-shifting circuits C_2–R_3–C_3 and L_2–R_4–L_3 convert the single-phase voltage across R_1 to four-phase star voltages at the grids of tubes V_1, V_2, V_3, and V_4. Since the tubes are biased to cut-off, their action is that of rectification. The phase displacement of the plate-current pulses is such as to provide a nearly uniform current in R_9. Circuit C_5–L_4–C_7 filters out the remaining current ripple. The function of V_5, V_6, V_7, and V_8 is similar to that described above for V_1, V_2, V_3, and V_4 except that frequency response is inverse. Polyphase rectification is employed since it is essential that the d-c currents in R_9 and R_{10} should have a minimum ripple. Also, in order to minimize reactive transients, it is desirable to use polyphase rectification in order that circuits C_5–L_4–C_7 and C_6–L_7–C_8 may have a low reactance.

The d-c voltage across R_9 and R_{10} is a function of the frequency applied to T_1. This voltage is center-tapped by R_{11} and R_{12}, and applied to the grids of V_9 and V_{10}. The plate currents flow through two windings of transformer T_2 and R_{13} and R_{14}. The voltage across R_{13} and R_{14} is applied to V_{13} and V_{14} to provide currents I_C and I_D, as shown in figure 3.

A voltage appears across the secondary winding of T_2 when the plate currents of

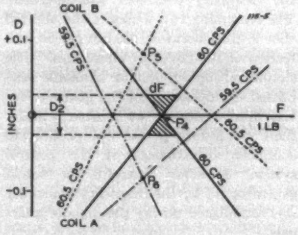

Figure 5. Equilibrant forces of balanced solenoid

V_9 and V_{10} are changing with respect to time. This voltage is therefore a function of the rate of change of system frequency with respect to time. It is amplified by V_{11} and V_{12}, and converted by V_{13} and V_{14} into currents I_A and I_B, also as in figure 3.

An alternative scheme for obtaining the load-sensitive component of control is the use of two capacitors and two resistors instead of the transformer T_2. This replacement of transformer T_2 is indicated in figure 8. A d-c current flows through R_{29} and R_{30} in response to a rate of change of potential across R_{13} and R_{14}. The voltage drop across R_{29} is then applied to the grid of V_{12}, while that across R_{30} is applied to V_{11}.

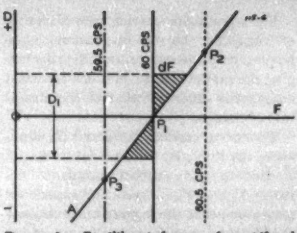

Figure 6. Equilibrant forces of centrifugal governor

The response of the load-sensitive component of control is not strictly accurate when capacitors are used instead of the transformer. Thus, for a suddenly-applied frequency rate of change, the voltage response at the grid of V_{11} is:

$$e = k_1 k_2 R_{29} C + k_2 R_{29} \epsilon^{-t/\tau C}$$

k_1 = time constant of applied rate of change of frequency
k_2 = voltage—frequency constant across R_{13} and R_{14}
k_3 = constant depending upon capacitor voltage conditions
C = series capacitance of C_{10} and C_{11}
$\tau = R_{29} + R_{30}$
t = time in seconds

It will be observed that the first term is directly proportional to the frequency rate of change. The second term is a capacitive transient during the initial period of the change while voltages are seeking their proper relationships. During tests, this transient was observed to be of the order of one-half second.

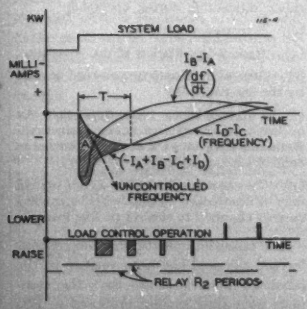

Figure 4. Operation of proposed governing system for abrupt load increase

Figure 7. Schematic of frequency controller

For a gradually varying rate of change of frequency, the response has one component proportional to and slightly lagging the rate of change, and one transient component similar to that of the abrupt rate of change.

The use of capacitors C_{10} and C_{11} eliminates the difficulty of core saturation of T_3 due to plate-current unbalance between V_9 and V_{10}. Operating experience may prove that the lagging and transient components present with the use of capacitors have no deleterious effect upon the quality of the frequency control.

The characteristics of the controller are readily variable. While maintaining the same normal current, the slopes of the I_A and I_B curves may be varied by adjusting R_{19} and R_{20}. Similarly, the slopes of the I_C and I_D curves may be varied with R_{15} and R_{16}. The current level of I_A and I_B is controlled by R_{24}. That of I_C and I_D is controlled by R_{25}. The normal operating points of the controller are independent of voltage variations at T_1. Supply-voltage variations affect only the slopes of the characteristic curves. The variation in slope is approximately proportional to the voltage variation. However, the effect of such variations is negligible.

Tests

The solenoid-operated control valve used in testing the frequency controller is shown in figure 9. The over-all length of this valve is seven inches. The operating piston, or servomotor, was operated by oil flowing through the two valve ports near the center of the valve. The component parts of the valve are shown in figure 10. This photograph shows the rear view of the brass valve cylinder. Oil under pressure was supplied to the center connection. Oil discharged from the operating piston passed through the outer two connections. The soft-steel valve plunger moves longitudinally through the two solenoid coils. The two center flanges match the valve ports shown in figure 9. Small diagonal holes were drilled through the flanges in order to revolve the plunger by the reaction of oil passing through. This rotation of the plunger maintained its freedom of movement. The two coils were connected to the frequency controller. Through the medium of the solenoid valve, the controller then controlled a piston-operated rheostat in the field circuit of a d-c shunt motor. This motor drove a 15-kva synchronous generator, from which the frequency controller was operated. The remaining two weeks of the allotted time in the laboratory did not permit perfection of the governor oil system. The simple oil-supply system available permitted the operation of the governor for less than a minute at a time. Under these conditions, it was not possible to complete adjustments of the control system. However, control of the motor-generator set by the frequency controller was established during these short intervals.

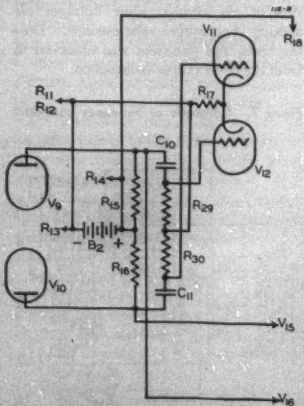

Figure 8. Alternative load-sensitive circuit for substitution in figure 7

Conclusions

A new electronic system of frequency control has been developed in the laboratory. It is believed that this control system can be adapted to standard hydraulic governors now in use.

The electronic frequency controller described in this paper provides movement of a solenoid plunger comparable to the controlling movement of a fly-ball governor. The controlling movement of a fly-ball governor depends upon change of speed. The controlling movement of the solenoid plunger depends upon both change of speed and rate of change of speed. It follows that a power-system governor controlled by such a solenoid should be sensitive to both frequency and changes in system load. A power-system governor controlled by a fly-ball governor is sensitive only to turbine speed.

The addition of the load-sensitive component of control eliminates one of the several time lags present in existing governing systems. The load-sensitive component of the solenoid motion actuates the governor to oppose hunting swings.

Figure 9. Solenoid-operated control valve used in tests

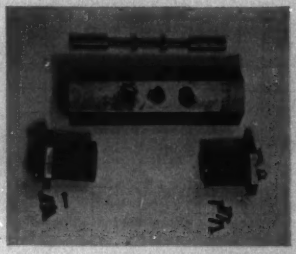

Figure 10. Component parts of control valve

It is believed that the solenoid described in this paper can be substituted, with no sacrifice of reliability, for the standard fly-ball governor head, provided that the latter is retained in a stand-by capacity.

The scheme of controlling machines in accordance with both speed and rate of change of speed is not new, as inertia governors have been used for many years in some applications other than electric power systems. It is believed, however, that the electronic control system herein proposed has the following advantages over the mechanical inertia governor:

(*a*). Response to rate of change of frequency separately adjustable during operation.

(*b*). Response to frequency deviation separately adjustable during operation.

(*c*). Increased sensitivity.

(*d*). Reduced oscillation of the governor.

(*e*). Several units may be governed at once by the one controller.

(*f*). Two or more controllers may be operated on the system at once, since adjustments may be made during operation to control load division.

(*g*). Two or more controllers on one system may be interlocked by pilot wires or carrier-current channels to control tie-line loads.

The essential operation of the controller and solenoid has been verified in the laboratory. It is hoped that the complete governing system proposed in this paper may be submitted to the test of operating experience in the near future.

Automatic Printing Ammeter

T. G. LE CLAIR
FELLOW AIEE

Synopsis: A new instrument has been developed which will automatically read and record in numerals, at predetermined time intervals, the ampere loading on 50 different electric circuits. This instrument also adds the readings on groups of circuits and prints these totals in columns beside the ampere load readings. The paper outlines briefly the reasons for developing such a device. The paper also describes, with the aid of schematic diagrams, the process by which the instrument obtains and prints all the measurements and totals on a single "log sheet."

Need for Compact Ammeter Records

THE rating of most electrical equipment is on an ampere basis. To determine when additional capacity in lines, transformers, or generators, is required on a power system, it is necessary to have an accurate record of past ammeter loads. For maximum usefulness, these ammeter records should be as compact and legible as possible for ready determination of the shape of the load curves and rate of growth.

In large power stations it is common practice for an operator to note and record on a "log sheet" the ammeter readings on all outgoing transmission lines at frequent intervals. When several of these outgoing lines supply the same load it is necessary to totalize the loads on all lines in a given group in order to estimate the load growth on the combined group. Figure 1 illustrates a typical group of substations fed by several lines from the same generating station. When 50 to 100 or more lines emanate from the same station the instrument readings must be recorded with a minimum of effort and in the most usable form. Recording instruments would be suitable for this purpose if their record could be compact enough.

Substations such as substation *A* in figure 1 may frequently be of an unattended type. In such a substation it is desirable to have ammeter records in convenient and compact form of the loading on transformers and distribution feeders. It is also desirable to obtain these records automatically, to avoid the expense of an attendant.

Paper 41-3, recommended by the AIEE committee on instruments and measurements and presented at the AIEE winter convention, Philadelphia, Pa., January 27-31, 1941. Manuscript submitted March 30, 1940; made available for preprinting October 26, 1940.

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The writer wishes to express his appreciation to Mr. H. M. Schaibly, whose quick perceptions and nimble fingers turned sketches and diagrams into a working machine. Appreciation is also due to Mr. J. R. Harrington and his associates for reducing the laboratory product to a flexible standardized design.

Available Types of Instruments

At present a number of types of instruments are available which can be used for obtaining compact records automatically. The most common type, of course, is the ordinary graphic instrument with one instrument installed on each circuit. These instruments are available with charts for various periods from one day up. There is also available a graphic instrument for ten circuits which, instead of drawing a load curve, puts on the graph paper a series of characters so that the line connecting the same characters is the equivalent of a graphic record. For totalizing the readings of several circuits, equipment is available by which either amperes or watts, a-c, can be converted to a d-c voltage, and the d-c voltages from several of these converters connected in series on a d-c instrument for a totalized reading.

In Chicago unattended substations the practice has been to use graphic instruments for ammeter records. In generating stations compact recordings of line readings are obtained by having an operator read a series of indicating instruments and record these readings on a log sheet in rows and columns. The usual arrangement is that each column represents the readings on a given circuit and each row is the series of readings taken at a given time. An increasing need was felt to relieve the operator of this burden in large stations, or to obtain these readings in substations where an operator is not on hand for 24 hours a day. This need resulted in the development of a measuring combination with the following basic principle:

Fundamental Principle of New Instrument

A single accurate measuring device is constructed which is automatically connected in turn to each of the circuits to be measured. The single measuring device is used in combination with a printer which records on a log sheet figures which are a measure of the magnitude of the current. The column position of a given reading on the log sheet signifies the circuit on which the reading was taken. The row position of the reading on the log sheet signifies the time when the reading was taken. The measuring device itself utilizes a balancing relay in which the current to be measured is balanced against the current from a standardizing source which is co-ordinated electrically to the printing device.

The totalizing of the readings is accomplished by means of additional mechanism which prints the total figures beside the readings which have been totalized. The new instrument eliminates the human error, both in the accuracy of the readings and in the timing of the periodic readings.

Laboratory Development

A simple experimental instrument was built first to show that the measuring principle would work. Later a full size model was made to record all the ammeter readings in one supervisory control substation. The complete model is shown in the photograph, figure 2. This model was constructed in the laboratory from various available standard parts. Recording is done on an ordinary typewriter on which the typewriter keys are operated by solenoids rather than by human fingers. The operating solenoids can be seen in the photograph directly under the typewriter keyboard at the top of the instrument cabinet. A sample of the record sheet obtained in this machine is

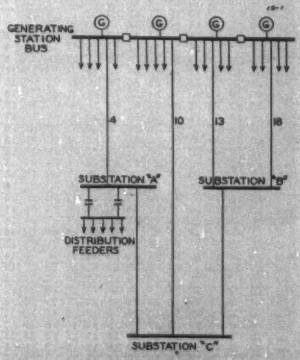

Figure 1. Typical transmission line group

The maximum loads on individual transmission lines may occur at different times due to different load characteristics on the three different substations

Figure 2. The first full-size automatic printing ammeter

This multicircuit printing ammeter, built in the laboratory, was the first one to record the loads on all transformers and outgoing 4,000-volt feeders of a complete substation

shown in figure 3. On this log sheet the first 12 columns of figures are the ammeter readings on each of the three phases of the four transformer banks. The remaining columns are the ammeter readings on the three phases of the outgoing 4,000 volt feeders. The spare circuit and circuit number 30 were not carrying load on the day this log sheet was taken. The figures on the log sheet are the ammeter readings in tens of amperes.

This machine, which has been in constant service for about three years, has given very satisfactory results and is adequate except for its home-made appearance. A detailed description of this printing ammeter and its method of operation will not be given in this paper because the principles are similar to those of the newer model which is appreciably more complete. The home-made instrument records the ammeter readings on 36 circuits and takes these readings every 30 minutes. At the end of the day, the log sheet for that day, in triplicate, is ejected from the machine automatically, and the log sheet for the following day is inserted ready for use.

Improved Design

After the laboratory model had been given a thorough trial in commercial operation, it was considered desirable to install a similar instrument in a generating

Figure 3. Typical log sheet from first full-size printing ammeter

This is a photograph of an actual log sheet showing the instrument readings on atypical day on all the circuits in an unattended substation

Daily Record of Ampere Loads on 4-Kv Circuits and Transformers

GOOSE ISLAND Substation Date 3/1/40

Cir. #	T2.#1			T2.#2			T2.#3			T2.#4			CIR.#43			CIR.#45			CIR.#41			CIR.#42			SPARE			CIR.#46			CIR.#5			CIR.#30								
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
12:00	7	6	7	14	14	16	13	13	13	13	12	13	7	6	5	13	12	16	10	10	11	0	0	0	0	0	0	12	12	11	0	0	0	0	0	0						
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7:30	10	9	9	18	17	16	17	16	17	17	16	17	8	8	8	12	11	13	12	13	13	0	0	0	0	0	0	22	21	19	9	7	8	0	0	0						
8:00	11	10	11	19	19	20	19	18	19	19	17	19	11	10	10	14	12	14	15	15	15	0	0	0	0	0	0	22	21	20	9	7	8	0	0	0						
8:30	19	18	18	31	31	33	30	28	30	29	27	29	18	14	14	20	19	22	24	26	26	11	11	11	0	0	0	27	27	24	13	12	13	0	0	0						
9:00	20	19	20	33	32	34	31	30	32	31	29	32	16	17	16	23	22	24	26	30	29	11	10	10	0	0	0	27	27	24	13	12	13	0	0	0						
9:30	19	18	19	32	32	33	31	29	31	30	28	30	16	17	16	21	19	22	27	29	29	12	11	10	0	0	0	25	25	22	11	10	11	0	0	0						
10:00	19	18	19	32	32	33	31	29	30	30	28	30	17	16	17	21	21	22	28	28	28	10	10	9	0	0	0	26	27	24	11	10	11	0	0	0						
10:30	20	19	20	33	34	35	32	31	32	31	29	31	19	18	17	23	21	25	30	30	30	10	9	9	0	0	0	25	26	23	12	11	12	0	0	0						
11:00	20	18	19	33	32	34	31	30	32	31	29	32	18	18	17	23	22	26	29	29	30	11	10	10	0	0	0	27	26	23	12	10	12	0	0	0						
11:30	20	19	20	33	33	36	32	31	33	31	29	33	18	18	18	22	22	24	30	31	31	10	10	11	0	0	0	27	28	24	12	10	12	0	0	0						
12:00	17	16	17	29	28	30	27	25	27	26	24	27	16	16	14	20	19	22	26	25	26	7	6	8	0	0	0	23	22	20	11	9	11	0	0	0						
12:30	17	16	17	29	28	30	27	25	27	26	24	27	16	16	14	20	19	22	26	25	26	7	6	8	0	0	0	23	22	20	11	9	11	0	0	0						
1:00	18	17	18	31	31	33	30	28	30	29	27	30	16	16	15	21	20	23	28	29	29	11	10	9	0	0	0	23	23	20	11	10	12	0	0	0						
1:30	19	18	19	31	31	33	30	29	31	29	28	30	16	16	16	22	22	24	28	29	29	10	11	10	0	0	0	24	22	20	11	10	11	0	0	0						
2:00	18	17	19	31	30	32	30	28	30	29	26	30	17	16	15	20	19	23	30	29	30	9	9	9	0	0	0	22	22	20	12	10	12	0	0	0						
2:30	17	16	17	29	28	30	28	26	28	28	25	28	16	16	15	21	20	23	27	27	28	10	10	9	0	0	0	20	20	17	11	9	11	0	0	0						
3:00	16	15	16	27	25	29	26	24	26	25	24	27	15	14	14	21	21	22	24	25	25	12	10	10	0	0	0	17	17	15	10	8	10	0	0	0						
3:30	16	14	14	26	26	26	24	23	24	24	22	24	14	14	13	20	19	21	23	23	23	10	10	10	0	0	0	14	14	12	10	9	10	0	0	0						
4:00	12	11	12	21	21	23	19	19	20	19	18	20	12	10	10	19	18	20	17	18	16	7	6	8	0	0	0	11	12	10	6	6	6	0	0	0						
4:30	10	9	9	17	17	18	16	15	17	16	15	16	11	10	10	21	16	19	14	16	16	6	5	4	0	0	0	10	11	9	0	0	0	0	0	0						
5:00	10	9	9	18	17	19	17	16	17	16	15	17	11	9	10	19	18	20	14	14	16	5	4	0	0	0	0	10	10	8	0	0	4	0	0	0						
5:30	9	8	9	17	16	18	17	16	17	17	16	16	12	9	9	19	17	21	13	13	14	6	3	0	0	0	0	10	11	9	0	0	3	0	0	0						
6:00	9	8	9	17	16	18	17	16	16	16	14	16	11	8	8	19	17	20	13	12	13	4	4	4	0	0	0	10	10	8	0	0	0	0	0	0						
6:30	9	8	8	17	16	17	16	16	16	16	13	16	10	8	8	20	17	20	12	12	12	4	4	0	0	0	0	9	10	8	0	0	0	0	0	0						
7:00	8	7	8	16	14	16	15	15	15	15	13	15	11	8	8	19	16	19	12	12	12	5	4	0	0	0	0	9	9	8	0	0	0	0	0	0						
7:30	9	8	9	17	16	18	16	16	16	16	13	16	11	8	8	20	18	21	12	11	12	8	4	0	0	0	0	9	9	8	0	0	0	0	0	0						
8:00	8	7	8	16	16	16	16	14	14	14	13	14	10	7	7	18	16	19	12	12	12	0	0	0	0	0	0	9	8	7	0	0	0	0	0	0						
8:30	8	7	7	16	14	16	16	14	15	14	13	15	10	7	7	20	16	20	11	11	12	3	0	0	0	0	0	9	9	7	0	0	0	0	0	0						
9:00	8	7	8	16	14	16	15	13	14	14	13	14	9	7	7	18	15	18	12	12	12	0	0	0	0	0	0	8	9	7	0	0	0	0	0	0						
9:30	8	7	7	16	14	16	15	13	14	14	12	14	9	7	7	16	16	19	12	11	12	0	0	0	0	0	0	8	9	8	0	0	0	0	0	0						
10:00	8	6	7	16	14	16	14	13	14	14	12	14	8	6	6	16	14	17	11	11	12	0	0	0	0	0	0	11	11	9	0	0	0	0	0	0						
10:30	7	6	7	14	13	14	14	13	13	14	12	13	8	7	6	16	15	17	11	10	11	0	0	0	0	0	0	10	10	9	0	0	0	0	0	0						
11:00	7	6	8	14	13	14	13	12	13	13	11	13	8	6	6	15	14	17	11	10	11	0	0	0	0	0	0	11	10	9	0	0	0	0	0	0						
11:30	7	6	6	14	13	14	13	11	12	12	11	12	7	6	6	14	14	16	10	9	10	0	0	0	0	0	0	10	10	8	0	0	0	0	0	0						

Date (12:00 A.M.)

station to record the ampere measurements on 45 outgoing transmission lines. However, in this station the indicating instruments are arranged in the same order on the switchboard as are the line switches on the busses in the station. The operator arranges the columns on his log sheet in the same order to avoid errors. Furthermore, the 45 lines are divided into ten different groups. The lines to a given group of load are not on adjacent switch positions, but are scattered throughout the station, as illustrated in figure 1, in order to diversify the supply to the load. This makes it necessary for the planning engineer, in using the log sheet, to look at scattered columns in order to totalize the loads in each group. Therefore, the design of the instrument was expanded to include a totalizing mechanism which records the total of the loads on the lines of each group in addition to the individual line loads.

The design was also increased in flexibility so that it would be a relatively simple matter to change the order in which the instrument readings appear on the log sheet or to change the groups of readings included in a given total. This was accomplished by the use of a plugging board arranged so that the secondary current circuits of transmission lines may be connected to the instrument in any order or grouping desired without changing any of the permanent wiring in the instrument. This is very convenient as new transmission lines are installed, or lines are cut over from one substation group to another, at intervals of a few months.

The new design also includes a printer which is designed as a part of the combined unit replacing the more cumbersome typewriter used in the early model. The result of this development is the instrument shown in the photograph, figure 4.

Parts of the Measuring Equipment

The measuring equipment in its finished form is shown in the photograph, figure 4. Figure 4*a* is a front view with the covers removed to show all of the operating parts of the equipment. Figure 4*b* is a rear view also with the cover removed, showing test switches. Each circuit to be measured is connected to a pair of these test switches, arranged so that the current circuit can be short-circuited and disconnected without disturbing any of the wiring within the instrument. The individual parts of the unit can be identified by reference to figure 5 which shows each element identified by name in the same physical position which it occupies in the photograph, figure 4*a*. For ease in describing the parts in the following method of operation, it is assumed that the current transformer ratios are 1:1 and that the instrument has a full scale reading of 100 amperes.

A contact-making clock is used to start the sequence of operations to obtain readings. This contact-making clock may be either a simple device making contact every 15, 30, or 60 minutes, or it may be set up with a definite program to take readings at variable intervals.

The master sequence switch is a rotary control switch used to determine the order in which the various functions of the instrument are performed. Each step in the process of taking measurements is controlled by this master sequence switch.

The circuit selector switch is a 50-point rotary switch with each of the circuits which are to be measured connected to one of the points or positions. A common connection leads from this switch to the measuring part of the equipment. Each circuit to be measured is normally short-circuited on itself in this selector switch but not connected to any other circuit. The circuit selector switch is used to connect each circuit in turn to the remainder of the equipment.

The balancing relay has two cores pulling at opposite ends of a balancing beam. The coil on one core is connected in turn to each circuit to be measured through the circuit selector switch; the current in this element is the current flowing in the measured circuit. The other core has two coils; each of these coils is supplied a variable current which is adjusted until the relay comes to a balance.

The measuring transformer is connected to a constant voltage a-c source and has two secondary windings to supply current to the two coils on the one core of the balancing relay through measuring switches.

The tens measuring switch is a rotary switch used to select steps on a resistor in the circuit from the measuring transformer to one coil of the balancing relay. Each step taken by this measuring switch increases the current in one coil of the balancing relay by ten amperes. Separate contacts on this measuring switch are connected to corresponding solenoid stops in the printing mechanism to select figures corresponding to the tens of amperes in the circuit.

The units measuring switch is similar to the tens measuring switch except that each step that this rotary switch takes varies the current in its corresponding coil of the balancing relay by one ampere instead of ten amperes. Separate con-

Figure 4a. Front view of standard model automatic printing ammeter

Covers have been removed to show mechanism. Printed forms feed from the front compartment through the printer mechanism at top. The typed figures on the log sheet are continuously visible through the glass cover when operating

Figure 4b. Back view of standard model automatic printing ammeter

Covers have been removed to show test switches, one pair for each circuit to be measured. Completed log sheets drop into the compartment above the test switches

tacts in this rotary switch are also connected to the solenoid stops in the printing mechanism.

The totalizing sequence switch is similar to the master sequence switch except that it controls the order of procedure for the printing of totals only.

Three totalizing rotary switches are used. One switch is used for totalizing units, the second one for tens, and the third for hundreds of amperes. Their method of operation is similar to that of an ordinary odometer. Each totalizing switch has contacts connected to the points in the printing mechanism to select the correct figures to be printed.

The printer consists essentially of a small type wheel which has numerals engraved on its periphery. This type wheel is caused to rotate after the instrument has struck a balance. Solenoid stops are used to position the type wheel so that the proper number is opposite the log sheet. The type wheel is then forcibly pressed against the paper and the carriage of the type wheel is shifted to the right one space ready for the next printing operation.

A number of control buttons are mounted on a panel in front of the printer. These buttons allow the operator to type line numbers at the top of the log sheet. There are also buttons for other manual control operations.

Method of Operation

An exact description of all the connections in the instrument and the method of operation would be unnecessarily long. An abbreviated description will show the essential steps in the operation without the detailed connections. The method of operation can be traced by reference to figure 6 in connection with the description. Figure 6 is a schematic or block diagram which shows each major element in relation to its place in the sequence of operations rather than in its physical position.

The numbers in parentheses inserted in the following paragraphs refer to corresponding numbers in circles in figure 6. The numbers represent the order of the steps in which the various parts of the equipment are brought into operation.

Assume that all circuits are dead and all rotary switches are in their normal or home positions. (1). The contact-making clock closes its contacts to start the taking of a reading. Through the operation of this clock and the master sequence switch the circuit selector switch connects the first circuit to be measured with one coil of the balancing relay.

The units measuring switch is first set in a position which supplies nine amperes in one coil of the balancing relay so that, if the current in the circuit to be measured is less than nine amperes, the balancing relay will trip. However, if the current in the circuit to be measured is greater than nine amperes, nothing happens.

(2). The master sequence switch through the balancing relay next starts the tens measuring switch to rotate. Each step that this switch takes increases the current in the corresponding coil of the balancing relay by 10 amperes, so that the corresponding total pull on the relay is successively 9 amperes, 19 amperes, 29 amperes, etc., until the balancing relay trips. For example, assume the current to be measured is 36 amperes. In this case the relay trips in the third position when the pull of 39 amperes overcomes the pull of 36 amperes. The tens totalizing switch is driven synchronously with the tens measuring switch, but no connection is made from the totalizing switch to the printer at this time. (3). The tripping of the balancing relay completes a circuit through the second group of contacts on the tens measuring switch to select the correct solenoid stop on the printing mechanism to print on a log sheet the number corresponding to the tens of amperes measured (in the example, the number 3).

(4). The master sequence switch transfers the operation to the units measuring switch. The units measuring switch is first placed in the position of zero current in the units coil so that the balancing relay then has a total current less than that in the circuit to be measured. (In the example 30 amperes.) The units measuring switch then rotates, increasing the current in its corresponding coil one ampere at each step until the balancing relay again trips. The units totalizing switch also operates synchronously with the units measuring switch but does not operate the printer. (5). The tripping of the balance relay then selects through the separate contacts of the units measur-

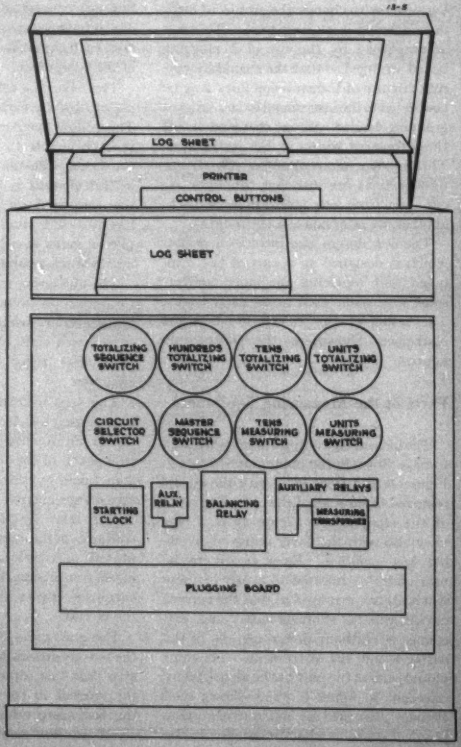

Figure 5. Outline sketch of printing ammeter

Outline sketch of front view in figure 4a on which each unit of the equipment has been labeled for identification

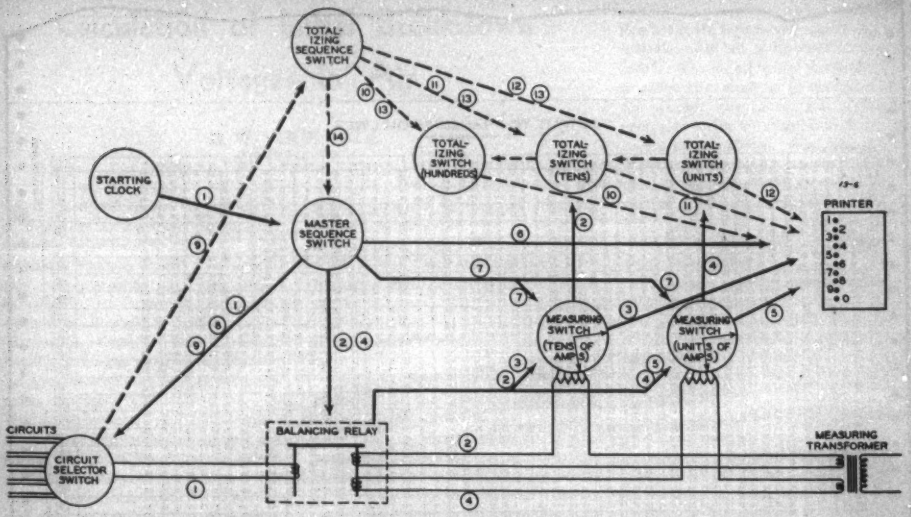

Figure 6. Block diagram for operating sequences of the instrument

Same elements are shown as in figure 5, except that elements are shown in relation to their sequence in the operation of the instrument and not in their physical position. Small numbers in circles refer to the order in which the steps are taken in the process of recording instrument readings. These numbers correspond to numbers in the description in the text

ing switch the correct solenoid stop on the printing mechanism to print the figure corresponding to the units of amperes measured (in the example, the number 6). (6). Then the master sequence switch operates the printer to space the carriage ready for the next reading.

(7). The master sequence switch next restores the tens and units measuring switches to the home position. However, the totalizing rotary switches are not restored to the home position at this time, but remain as set by the first reading.

The steps just described complete the cycle of operation for taking and printing the instrument reading for one circuit. (8). The master sequence switch next advances the circuit selector switch one step in order to disconnect the first measured circuit from the balancing relay and connect the second circuit to be measured to the balancing relay. The operation of measuring and printing is repeated for the second circuit exactly as for the first.

The circuit selector switch is equipped with separate contacts by means of which a total reading can be taken after the instrument reading on any predetermined circuit. For example, it may be assumed that a total is to be taken of the first four readings. In this case the fourth instrument reading is taken according to the same procedure as before, but the master sequence switch does not complete its rotation. (9). Through the auxiliary contact in the fourth position of the circuit selector switch the master sequence switch transfers control to the totalizing sequence switch. The totalizing sequence switch then connects to the printer in turn the (10) hundreds, (11) tens, and (12) units totalizing switches to record the positions of the dials, which correspond to the total of the figures printed for the first four instrument readings. (13). The totalizing sequence switch then returns the three totalizing switches to the normal or home position and (14) transfers control back to the master sequence switch to complete its travel and go on with the next reading.

Additional equipment which is relatively simple and not shown on the block diagram is used to return the printer carriage to the home position, advance the log sheet one line for the next reading, and de-energize the instrument at the end of a complete set of readings. Other auxiliary equipment is also used to eject one log sheet from the printing ammeter and insert a new one at the end of a specified period when the log sheet is filled.

This description of the sequence of operation may create an illusion as to the length of time required for a complete set of readings. Actually the relays and switches operate much faster than the human eye can follow them. To print the readings of 45 transmission lines, grouped into ten groups, and their totals requires about two minutes total time, or two seconds per individual reading or totalizing printing.

A completed log sheet obtained from the instrument is illustrated in figure 7. The printing mechanism types across this log sheet every 30 minutes and at the end of the reading advances the sheet automatically to the next line. The right-hand and left-hand columns of figures on the printed form are the hours of the day at which each row of instrument readings was recorded. The typed numbers in the top row are the numbers of the outgoing transmission lines and the numbers below these column headings are the ampere readings in ten's on each line. The letter "T" above a column represents the column of totals for the group of line readings directly to the left of this column. For example, the first total is of the ampere readings on line numbers 11, 22, 32, 74, and 93. The picture shows also the top of the form for the following day. When the sheet is advanced automatically at the end of the day, the next form is ready for the first reading at 12:30 a.m. and the log for the day can be torn off at the perforations. In unattended substations the continuous forms can accumulate for several days in the compartment back of the printer until an operator arrives to remove them.

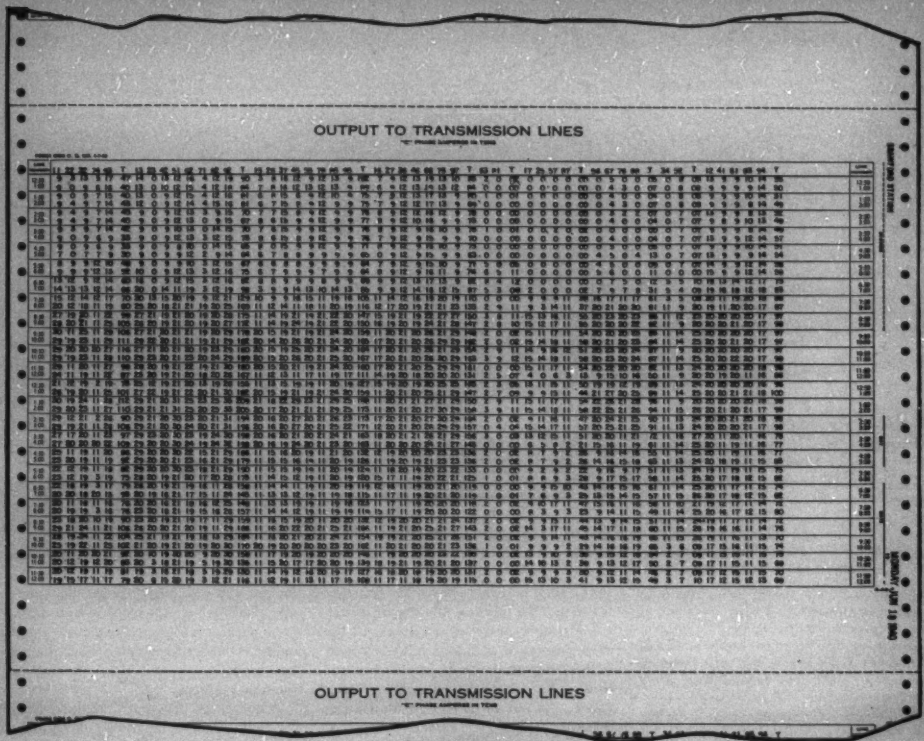

Figure 7. Typical log sheet obtained from the automatic printing ammeter

Photograph shows the log sheet for one day with the bottom edge of the log sheet for the preceding day and the top of the sheet for the following day above and below the perforated lines on the continuous form. Column headings are the numbers of the outgoing transmission lines

The complete printing ammeter contains a number of relay contacts. However, not many of these contacts are involved in a particular operation. The printing ammeter shown in figure 2 has been in regular operation for about three years and has been nearly free of trouble since the initial period when it was subject to frequent tampering for the benefit of curious visitors. The instrument shown in figure 4 has been in service nearly a year. It appears that the maintenance costs on one printing ammeter for a multiplicity of lines will compare very favorably with the maintenance cost on a number of indicating ammeters, one for each line.

Fields of Usefulness

One of the major fields in which this device is very useful is in automatic or supervisory control substations. In such substations the installed cost of this multiple-circuit instrument should approximate the installed cost of individual instruments on each circuit. For such installations a traveling operator has only one instrument from which to remove records. The single record sheet is much more convenient to handle, mail, and file, than a large number of graphic instrument charts containing similar information.

In generating stations or larger substations which are attended, the elimination of the human element results in a more accurate and more legible record. All readings are taken on scheduled time as determined by the clock contacts whether or not the operator is interrupted by the telephone or other operating duties. In busier galleries there may be a saving of labor.

The instrument can be made in more portable form so that it can be used for special tests or for periodic routine load checks if desired. The plugging board, similar to a telephone switchboard, makes it relatively simple to connect circuits in any desired order for special test purposes.

For any of these applications, the instrument is appreciably more accurate than the standard switchboard type of instrument. In a device such as this where only one measuring element is used for a multiplicity of circuits, it is economical to have not only a more accurate, but a more rugged measuring element. The laboratory model of the instrument has been in service about three years, during which time the measuring element has been dismantled and put back together for check, and it has not required any recalibration to maintain an accuracy of plus or minus one per cent.

Where records are used in more than one office for various purposes, the instru-

Calculation of Initial Breakdown Voltages in Air

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ALTHOUGH spark-over and corona starting voltages can be predetermined satisfactorily in cases for which empirical formulas or curves are available, a more generally applicable method is needed. An approach to such a method is through a modification of Townsend's theory[1,14] which, though possibly lacking in rigor, suffices in many cases for the accurate calculation of breakdown voltages. Calculations of this kind by Schumann[2] in 1923 for air in nonuniform fields were not entirely successful because of inadequate knowledge of the Townsend coefficients for air, a deficiency now remedied.[3,4,5] Loeb has discussed the modified Townsend theory at length and has applied it quantitatively to nitrogen in uniform fields.[6,7,20]

The present paper outlines the theory and shows that the initial breakdown voltage may be calculated using two quantities characteristic of the gas for cases where the field, if nonuniform, converges toward the cathode. Formulas expressing one of the characteristic quantities for air, the Townsend coefficient α, are assembled, and a formula for the second quantity is deduced from an analysis of published spark-over gradients for plane gaps. The method is applied to two cases and the results are shown to be in agreement with experiment

Paper 41-4, recommended by the AIEE committee on basic sciences and presented at the AIEE winter convention, Philadelphia, Pa., January 27-31, 1941. Manuscript submitted October 30, 1939; made available for preprinting October 24, 1940.

This paper is part of a dissertation presented for the degree of doctor of engineering in Yale University, 1940.

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1. For all numbered references, see list at end of paper.

Fundamental Considerations

Electrical breakdown of a gas depends primarily on the presence of free electrons. Their concentration, normally very small, is determined by the relative activity of the ionizing agents, radioactive emanations for instance, and the effects which cause them to disappear. Besides recombining directly with positive ions, the free electrons may be swept away by an applied field, and in air they may form negative ions by attachment to neutral oxygen molecules.

In an electric field, the electrons may gain sufficient energy to excite or ionize molecules in their paths. When the gradient exceeds 15 kilovolts per centimeter in atmospheric air, the electrons are more likely to ionize than to become attached to oxygen molecules. Then each electron as it travels toward the anode continues to make ionizing collisions, liberating more electrons which in turn multiply similarly. A single electron set free by an external agent can thus initiate an *electron avalanche* consisting of a cluster of electrons which grows rapidly as it advances and which leaves a trail of positive ions. With the field strength occurring at breakdown, an avalanche has a velocity of the order of 10^7 centimeters per second, while the positive ions left in the trail move back toward the cathode with but a hundredth of this speed. The negative ions resulting from attachment of electrons to molecules and the positive ions cannot gain sufficient energy to ionize by collision in fields attained at breakdown. The ions generated by a single avalanche disappear quickly, causing merely a small pulse of current, and the passage of a single or even many separate avalanches from cathode to anode does not necessarily result in breakdown.

There are, however, *secondary mechanisms* by which an avalanche can cause the liberation outside itself of electrons which may start new avalanches. If each avalanche initiated causes the release of at least one secondary electron in a favorable location, a self-sustaining discharge current, that is breakdown, can result from the liberation of a single electron by an external agent. The exact nature of the secondary mechanisms active in given circumstances remains a matter for speculation[20] but a few generalizations are safe.

Two kinds of breakdown are recognized which, though they may merge, are distinct as to secondary mechanisms believed to be active. One, the *cathode initiated type*, occurs in the corona around negative electrodes and in the normal or static spark-over of short gaps. In it, positive ion bombardment or radiation from molecules excited by the avalanche causes emission of secondary electrons from the cathode surface. The other type, of which the lightning leader stroke is a manifestation, is the *positive streamer*, and occurs in the corona around positive electrodes, in the normal spark-over of long gaps, and in short gaps when more than the initial breakdown voltage is very suddenly applied. The secondary mechanism for this type is more complicated and probably involves photoelectric action in the gas and intensification of the

ment will produce four or five good carbon copies. In the Chicago substation three copies of the record are made, one for the operating department, one for the substation load record, and one for the distribution feeder load record. In the generating station four copies are made.

The printer need not be installed in the same cabinet with the measuring equipment. It is practicable to locate the measuring equipment near the control wiring and have the printer make the record sheet in a different room.

The present instrument is confined to ampere readings. However, it will probably be extended to other quantities such as volts or watts when the need arises.

The totalizer element of the instrument was a relatively inexpensive addition. It proved to be a valuable time saver for planning engineers because it eliminated the need of totalizing the figures in scattered columns. The hour of maximum load is obtained by scanning the total column only, and load analysis is usually made for only the maximum load.

Conclusion

This new automatic printing ammeter produces a compact record of the load on any number of circuits up to 50, with readings arranged in the form of a column for each circuit and a line for each hour of the day. The load record also includes totals for groups of lines. The following are incidental benefits derived from the use of the instrument: greater accuracy, greater legibility, duplicate records, and uniform timing of readings.

field by the space charge of successive avalanches.

This paper is concerned only with the calculation of the voltage at which cathode initiated breakdown occurs, and the question of whether the initial breakdown is a complete spark-over or a stable corona discharge is not considered.

The Townsend Coefficient α

The number of electrons n comprising an avalanche increases with distance s along the path at a rate proportional to the number already present. Thus

$$\frac{dn}{ds} = \alpha n \qquad (1)$$

where α, the Townsend coefficient, is dependent on the field strength as well as the density and kind of gas. The path of the avalanche is a line of electrostatic force if the gas density is high enough so that the electron mean free path is small compared to the radius of curvature of the field line, a condition likely to be true in practice. For an avalanche initiated by a single electron from the cathode, $s=0$, integration along a line of electrostatic force gives for the number of electrons when the avalanche reaches the anode, $s=S$,

$$n = e^{\int_0^S \alpha ds} \qquad (2)$$

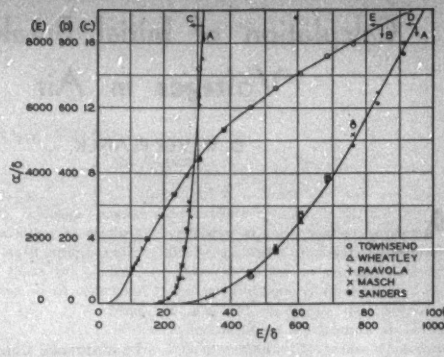
where α through its dependence on field strength is a function of s. The number of positive ions left in the trail of the avalanche is practically equal to n, although accurately it is one less since the initiating electron was emitted from the cathode.

If the avalanche grows large enough, the space charge of the ions causes the field to vary within the avalanche so that α is not the same for all of the electrons, and equation 2 is no longer true. However, certain calculations,[9] too lengthy to be included here, indicate that the field distortion caused by a single avalanche is negligibly small in a wide range of practical cases.

The method of measuring α, originated by Townsend,[1b] is based on the application of equation 2 to the continual succession of avalanches initiated by a current of photoelectrons emitted from the cathode of a parallel plane gap. Townsend found that α is related to field strength E and gas density δ by $\alpha/\delta = F(E/\delta)$ where the function F depends on the kind of gas.[1c]

Townsend,[1c,10] Wheatley,[10] Paavola,[4a] Masch,[4] and Sanders[3] have determined α for air with the results shown in figure 1. In this paper E is in kilovolts per centimeter and δ is the density relative to that at 760 millimeters and 25 degrees centigrade, units more convenient for calculations on atmospheric discharges than those employed by physicists, which are respectively volts per centimeter and millimeters of mercury. Density is used rather than pressure because mean free path, the significant factor, depends on density in general but on pressure only at constant temperature.

Figure 1. The Townsend coefficient α for air



The curves in figure 1 are plotted using the following empirical formulas which serve to express α for air in the ranges of E/δ indicated.

Range I. $15 < E/\delta < 25.8$
$\alpha/\delta = a_1 e^{b_1 E/\delta}$
$a_1 = 1.67 \times 10^{-6}$
$b_1 = 0.47$

Range II. $25.8 < E/\delta < 78.7$
$\alpha/\delta = a_2 (E/\delta - b_2)^2$
$a_2 = 0.166$
$b_2 = 21.5$

Range III. $78.7 < E/\delta < 200$
$\alpha/\delta = a_3 (E/\delta - b_3)$
$a_3 = 19.0$
$b_3 = 50.0$

Range IV. $200 < E/\delta < 467$
$\alpha/\delta = a_4 e^{-b_4 \delta/E}$
$a_4 = 1.08 \times 10^4$
$b_4 = 266$

Range V. $E/\delta > 467$
$\alpha/\delta = a_5 (E/\delta)^{1/2} - b_5$
$a_5 = 322$
$b_5 = 850$

(3)

Formulas for α similar in form to the first, second, fourth, and fifth of these have been given by Sanders,[3] Paavola,[4b] Townsend,[1d] and Loeb[6a] respectively, but here the constants have been adjusted for agreement with all of the data. The formulas result in curves tangent to each other at the given limits, so that for convenience in calculation the limits may be shifted slightly without serious loss of accuracy.

For $E/\delta < 15$ it is assumed that $\alpha/\delta = 0$; it is certainly less than 0.02, the value at $E/\delta = 15$.

Cathode Initiated Breakdown

In cathode initiated breakdown a single electron released by an external ionizing agent starts an avalanche from the cathode surface. As this avalanche crosses the gap, the secondary mechanisms come into play and if they release at least one electron from the cathode, one or more new avalanches may follow. When the secondary mechanisms are sufficiently active to assure the continued repetition of this process without further action by the external agent, breakdown results.

One of the two important mechanisms by which an avalanche can cause electron emission from the cathode is through bombardment by the positive ions left in the trail. The probability that a positive ion striking the cathode will cause an electron to be released is a function of the kind of surface and the energy of the impinging positive ion. The mean free path being small, the energy for a given gas is proportional directly to the gradient E_c at the cathode surface and inversely to the density of the gas; that is, to the ratio E_c/δ. The probability that a released electron will escape diffusion back to the cathode or attachment to a neutral molecule and be able to start an avalanche also depends on E_c/δ.[4b] Thus the number N of positive ions which must strike the cathode to assure the initiation of one secondary avalanche is a function of E_c/δ and is independent of gap geometry. The condition for breakdown is that the number of positive ions left in the trail of the original avalanche must equal or exceed the number N; that is, with the aid of equation 2,

$$e^{\int_0^S \alpha ds} \geq N \qquad (4)$$

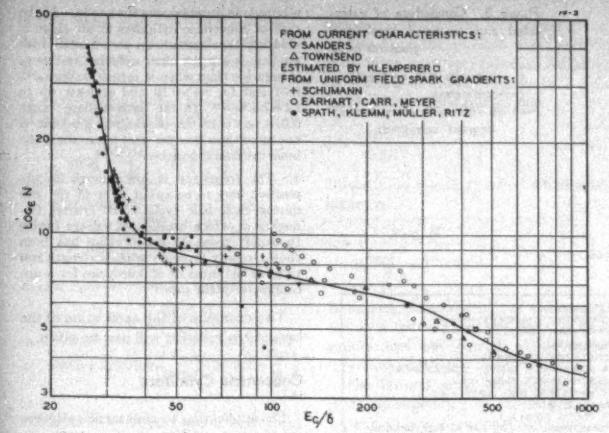


Figure 2. Log$_e$ N for air

a criterion given in the literature in various equivalent forms.[1c,4c,5a]

The other important mechanism for the release of secondary electrons at the cathode is through photoelectric action of radiation from molecules excited by the avalanche.[8a] It will now be shown that equation 4 applies approximately for this process also. The number of molecules excited by the impact of electrons is roughly proportional to the number ionized,[8d] hence the total radiation from the trail of an avalanche is proportional to the number of positive ions formed, exp $(\int_0^S \alpha ds)$. Radiation reaching the cathode surface has its greatest intensity near the starting point of the avalanche, this being nearest to all parts of the trail because the avalanche path, a line of force, necessarily starts normal to the cathode surface and in practical cases never curves sharply. For a given cathode gradient and avalanche size, the intensity of radiation at the cathode should depend on the variation of gradient with distance from the cathode because this would affect the distribution of excited molecules along the avalanche trail. However, this effect of gap geometry is probably not great and is neglected here. The number of electrons released per unit of radiation reaching the cathode depends on the properties of the surface, and as before the probability that an electron will escape attachment or diffusion back to the cathode and be able to start a new avalanche depends on E_c/δ. Thus, as with positive ion bombardment, the probability that a secondary avalanche will be initiated is a function of E_c/δ and is proportional to the number of positive ions formed by the original avalanche, and consequently equation 4 is also the criterion for breakdown by the photoelectric mechanism.

With either mechanism the secondary avalanches are most likely to be initiated near the starting point of the original avalanche, for this part of the cathode is both where the positive ions strike and where the radiation is most intense. The two mechanisms may act jointly but evidence that the time lag for spark formation in uniform fields is less than the gap transit time for a positive ion makes the photoelectric mechanism more likely,[6a] although for corona on small negative wires, positive ion bombardment probably predominates.[7]

The Number N for Air

The criterion 4 implies that breakdown occurs when exp $(\int_0^S \alpha ds)$, the number of electrons in an avalanche which has crossed the gap, equals or exceeds N, a number characteristic of the gas and dependent on the cathode gradient to density ratio E_c/δ, but independent of the type of field.

To obtain a knowledge of N for air, equation 4 was applied as the criterion for a spark in uniform field, when if the gap length is S the relation

$$\log_e N = \alpha S \qquad (5)$$

follows at once. Here the right member can be determined for any value of E/δ with the aid of the empirical formulas 3 for α/δ and abundant information in the literature relating the quantities $S\delta$ and E/δ for sparks in uniform fields. In this way N can be determined for a wide range of E_c/δ, since in this case E_c and E are identical. The data used were the well known curve by Schumann[3c] based on a survey of the work done prior to 1922; results by Earhart,[3d] Meyer,[3e] and Carr[3f] which fall outside the range of Schumann's curve; and results obtained since 1922 by Spath,[10] Klemm,[11a] Müller,[12a] and Ritz.[13]

In figure 2 log$_e$ N has been plotted rather than N because it is the former that is desired for general use. While the points show considerable dispersion, a mean curve can be determined with fair certainty. This curve is expressed in the range $26<E_c/\delta<250$ by the empirical formula

$$\log_e N = 10.0(25\delta/E_c)^{0.9} + 43.0(25\delta/E_c)^{2.8} \qquad (6)$$

The last term is negligible when $E_c/\delta>60$.

When positive ion bombardment is the predominant secondary mechanism, the reciprocal of N is identical with the probability γ that a positive ion impact will release an electron from the cathode. A few values of γ for air obtained from pre-breakdown current characteristics are reported by Sanders,[3] and a few others may be calculated from similar data by Townsend.[1c] Points obtained from these and from an estimate of γ attributed to Klemperer[14] are included in figure 2.

Application of the Breakdown Criterion

For the calculation of initial breakdown voltages the criterion 4 is more convenient in the equivalent form

$$\int_0^S \alpha ds \geq \log_e N \qquad (7)$$

The greater the inequality, the more nearly certain is breakdown, but since the left member turns out to be a function which increases very rapidly with applied voltage, the equality may be taken for practical purposes as the criterion for breakdown to be certain.

The left member of equation 7 depends on the field intensity E at every point along a line of force between the electrodes, and the right on the intensity E_c at the cathode end of this line. The field intensity, given by electrostatic theory, is proportional at every point to the voltage between electrodes if the field distortion caused by single avalanches is neglected and if no other space charges are present. Thus equation 7 gives the voltage implicitly or, if desired, the gradient at any point such as the cathode, at which breakdown will occur along the line of force considered. The breakdown voltage for

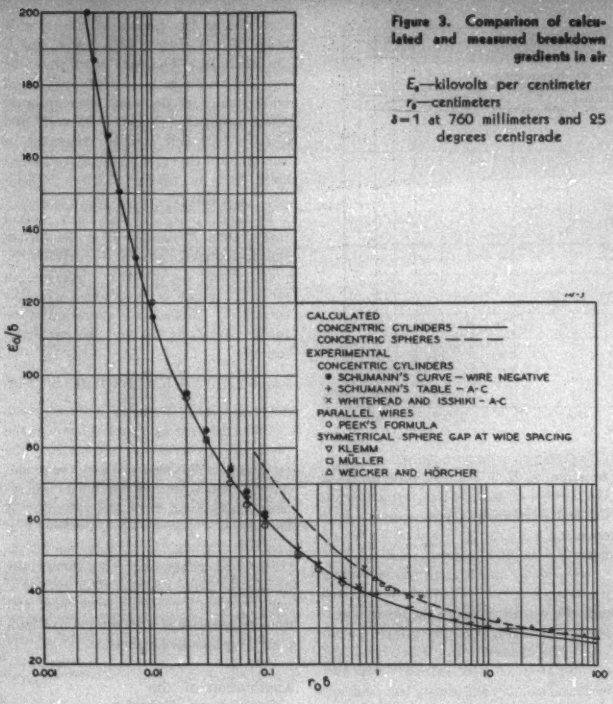


Figure 3. Comparison of calculated and measured breakdown gradients in air

E_0—kilovolts per centimeter
r_0—centimeters
$\delta=1$ at 760 millimeters and 25 degrees centigrade

a given gap is found from the line of force for which equation 7 gives the lowest voltage. In many practical cases the proper line can be selected by inspection as the shortest one.

The integration corresponds to the entire growth of an avalanche, and consequently in general is from the cathode $s=0$ along a line of force, to the anode $s=S$. However, in air if the field diverges from the cathode to such an extent that E/δ becomes less than 15 before the anode is reached, the upper limit may be taken at the point where $E/\delta=15$, because $\alpha=0$ for $E/\delta<15$.

Special consideration is necessary if the field converges again beyond a region where $E/\delta<15$. At the lower field intensities, $E/\delta<15$, the electrons are more likely to become attached to oxygen molecules than they are to ionize by collision. With no field applied, the electrons survive on the average during the motion of thermal agitation only about ten collisions with oxygen molecules before becoming attached.[15] Moreover, the electrons do not become detached from negative ions when E/δ is less than about 70.[8b] Then since negative ions do not ionize by collision in fields normally attained, an avalanche having passed through a region of appreciable extent where $E/\delta<15$ would not grow further unless it passed into a region where $E/\delta>70$. In such cases equation 7 is not directly applicable.

The breakdown criterion, equation 7, is applicable to impulse as well as to direct voltages, provided that:

1. An adequate supply of initiating electrons is maintained by the external ionizing agents.

2. The applied voltage does not change appreciably during the extremely brief time of transit of the avalanche. In the case of sphere-gaps the impulse breakdown voltage is the same as the static value if the time from the zero of voltage to the crest exceeds about two microseconds.[16]

The criterion also gives the crest value of alternating voltage at which breakdown will occur with a given electrode considered as cathode, provided in addition that:

3. Breakdown has not already occurred during the previous half cycle when the electrode in question was the anode. In the case of concentric cylinders in air there is evidence that breakdown occurs at a lower gradient when the inner cylinder, radius r_0, is negative than when it is positive for $r_0\delta<0.01$ and for $r_0\delta>0.19$ and at least up to $r_0\delta=7.0$.[8f,17,18] In the intermediate range $0.01<r_0\delta<0.19$ the breakdown gradient is not more than four per cent lower when the inner cylinder is positive.[8f]

4. The frequency is low enough for the positive ions to be swept clear of the gap during each half cycle. The critical frequency at which breakdown voltage begins to depart from its static value has been shown to vary inversely with gap length and to be of the order of 50 kilocycles for a one centimeter plane gap.[19]

Two examples of the application of the breakdown criterion will now be given.

Concentric Cylinders

For application to concentric cylinders the inner of which is negative, the breakdown criterion, equation 7, is expressed in terms of the radius r, the co-ordinate along a line of force. Thus

$$\int_{r_0}^{r_1}\alpha dr=\log_\epsilon N \tag{8}$$

where r_0 and r_1 are respectively the radii of the inner and outer cylinders. The right member is a function of the cathode gradient which in this case is the gradient E_0 at the inner cylinder.

Because α is a function of the field intensity E, it is convenient to change the variable of integration from r to E by means of the relation $E=E_0r_0/r$ for the field between concentric cylinders. Equation 8 then becomes

$$\int_{E_0}^{E_0r_0/r_1}\alpha(-E_0r_0E^{-2}dE)=\log_\epsilon N \tag{9}$$

Then

$$r_0=\frac{\log_\epsilon N}{E_0\int_{E_0r_0/r_1}^{E_0}\alpha E^{-2}dE} \tag{10}$$

which for any given ratio of radii, r_0/r_1, relates the radius r_0 of the inner cylinder to the gradient E_0 at which a negative discharge will start.

The integral can be evaluated graphically as the area under a curve derived directly from α figure 1, or analytically, using the empirical formulas 3 for α as is done in appendix A.

An important case is where the outer cylinder is quite large compared to the inner. When it is large enough so that at its surface $E/\delta<15$, that is $r_1>(E_0r_0/15\delta)$, α is zero in the space adjacent to the outer cylinder and the integration can be started at $E=15\delta$ instead of at $E=E_0r_0/r_1$, making the result independent of r_1.

In this case when the integrals from appendix A and numerical coefficients from the formulas 3 and 6 are substituted in equation 10 and the result arranged for easy computation, there is obtained for E_0/δ between 25.8 and 78.7

$$r_0\delta = \frac{10.0\left(\frac{25\delta}{E_0}\right)^{1.3}+43.0\left(\frac{25\delta}{E_0}\right)^{10.6}}{0.226+103.75\left(\frac{E_0}{25\delta}-1\right)-178.45\times \log_e\left(\frac{E_0}{25\delta}\right)+76.73\left(1-\frac{25\delta}{E_0}\right)} \quad (11)$$

and for E_0/δ between 78.7 and 200

$$r_0\delta = \frac{7.92\left(\frac{80\delta}{E_0}\right)^{1.3}}{236.8+1{,}520\log_e\left(\frac{E_0}{80\delta}\right)-950\left(1-\frac{80\delta}{E_0}\right)} \quad (12)$$

The results of theory and of experiment are compared in figure 3. The solid curve is a plot of equations 11 and 12. The experimental points are from a curve by Schumann,[2] based on work of Farwell, Schaeffers, Whitehead and Brown, and Whitehead and Lee; from a table by Schumann[16] based on researches by himself, Peterson, and Peek; from empirical formulas by Whitehead and Isshiki[17]; and from the empirical formula for parallel wires by Peek.[20] Excepting the last, all of the data are for concentric cylinders, and for either a negative inner cylinder or alternating voltage. The greatest departure of any point from the curve is about four per cent, and at that place there are other points on the opposite side. Thus the theoretical curve is in substantial agreement with experiment throughout a range of $r_0\delta$, the extremes of which are in a ratio of about 6,000 to 1.

An empirical formula often used to correlate corona starting gradients for cylinders is of the type

$$E_0/\delta = A+B(r_0\delta)^{-1/2} \quad (13)$$

where A and B are constants which have been given various values.[17,20] A plot of E_0/δ against $(r_0\delta)^{-1/2}$ as calculated from equations 11 and 12 shows some deviation from the form of equation 13, for as shown in figure 4, instead of having a constant value B, the slope first decreases considerably and then increases very slightly. Equation 13 thus does not agree with the theory although it may serve as a very convenient approximation over limited ranges.

Concentric Spheres

The breakdown criterion, equation 7, written for concentric spheres is identical with equation 8 except that r is the spherical instead of the cylindrical radius. Letting E_0 be the gradient at the surface of the inner (negative) sphere of radius r_0, the gradient at radius r is given by $E=E_0(r_0/r)^2$ from which it follows that

$$dr = -\frac{r_0E_0^{1/2}dE}{2E^{3/2}} \quad (14)$$

Substituting this in equation 8 and solving for r_0:

$$r_0 = \frac{2\log_e N}{E_0^{1/2}\int_{15\delta}^{E_0}\alpha E^{-3/2}dE} \quad (15)$$

In making the lower limit of the integral 15δ, it is assumed that the region of ionization does not extend to the outer (positive) electrode.

The integral must be separated into parts corresponding to the ranges of α formulas 3, and when the integrations are carried out as shown in appendix B, there results for the case where E_0/δ is between 25.8 and 78.7

$$r_0\delta = \frac{10.0\left(\frac{25\delta}{E_0}\right)^{9.7}+43.0\left(\frac{25\delta}{E_0}\right)^{19.1}}{0.1049+34.58\left[\left(\frac{E_0}{25\delta}\right)^{1/2}-1\right]-178.45\times \left[\left(\frac{E_0}{25\delta}\right)^{1/2}-1\right]+76.73\left[1-\left(\frac{25\delta}{E_0}\right)^{1/2}\right]} \quad (16)$$

This result is plotted as the dashed curve in figure 3. The experimental points shown, taken from curves presented by Klemm,[11b] Müller;[19b] and Weicker and Hörcher,[21] are the limiting breakdown gradients approached at wide spacings in the symmetrical gaps between equal spheres at potentials equally above and below ground.

The justification for comparing results measured for symmetrical sphere-gaps with those calculated for concentric spheres, as well as for including experimental points for parallel wires with the curve calculated for concentric cylinders, is as follows:

1. As the spacing of the symmetrical gap is increased, the field in the region surrounding the negative electrode where the ionization occurs approaches that for concentric electrodes.

2. The electrons passing into mid gap where the field is weak become attached to neutral molecules forming negative ions which cannot ionize by collision as they go on into the intense field around the positive electrode.

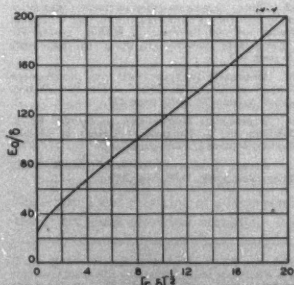


Figure 4. Calculated results for concentric cylinders tested for agreement with empirical formula of the type $E_0/\delta = A+B(r_0\delta)^{-1/2}$

Conclusion

The initial breakdown voltages for two distinct types of nonuniform field have been calculated accurately by means of the breakdown criterion, equation 7, and the data contained in formulas 3 and 6, for as shown in figure 3 the results are in excellent agreement with experiment. In addition to the two examples given here, the method is being applied to breakdown between sharp edged electrodes, and it is hoped to present the results when the experimental confirmation is complete.

For the successful application of the method it is fortunate that the voltage calculated from equation 7 is relatively insensitive to changes in N because this quantity depends on mechanisms whose exact nature is somewhat obscure. Consequently the agreement of theory and experiment shown in figure 3 is not offered as proof of the correctness of the physical picture used in developing the method. There is evidence[22] that in plane gaps where $S\delta>0.3$, which corresponds approximately to $E_0/\delta<35$, breakdown is not cathode initiated as assumed here but proceeds by streamer formation. However, as may be seen in the lower right hand portion of figure 3, the method yields correct results when $E_0/\delta<35$ in spite of the possible lack of rigor in this range.

Finally it should be noted that while the data presented pertain to breakdown in air, the method is general and applicable to any gas for which the characteristic quantities α and N are known.

Appendix A—Integration for Concentric Cylinders

The integral in equation 10 must be separated into parts corresponding to the ranges in which the formulas 3 for α apply. The extreme limits of integration are the gradients at the outer and inner cylinders, while the intermediate limits of the partial integrations are the limits of the ranges of α.

The number of ranges which must be included depends on the case considered.

When the gradient at the outer cylinder is less than 15δ and unless the inner cylinder is extremely large, the integration must go completely through range I and terminate in ranges II or III. For range I

$$a_1\delta\int_{15\delta}^{25.8\delta} e^{b_1E/\delta}E^{-\frac{1}{2}}dE = -a_1e^{b_1E/\delta}\delta/E\Big]_{15\delta}^{25.8\delta} + b_1a_1\int_{15\delta}^{25.8\delta} e^{b_1E/\delta}E^{-1}dE$$

$$= -a_1e^{b_1E/\delta}\delta/E\Big]_{15\delta}^{25.8\delta} + b_1a_1[\overline{\mathrm{Ei}}(25.8b_1) - \overline{\mathrm{Ei}}(15b_1)] \quad (17)$$

where the exponential integral function $\overline{\mathrm{Ei}}$ is defined and tabulated by Jahnke and Emde.[22a]

The integration in range II is

$$a_2\delta\int_{25.8\delta}^{E_0} (E/\delta - b_2)^2E^{-\frac{1}{2}}dE = a_2[E/\delta - 2b_2\log_e(E/\delta) - b_2^2\delta/E]_{25.8\delta}^{E_0} \quad (18)$$

For very small inner cylinders the integration must go beyond range II. Then the upper limit of 18 becomes 78.7δ instead of E_0 and integration into range III is necessary.

$$a_3\delta\int_{78.7\delta}^{E_0} (E/\delta - b_3)E^{-\frac{1}{2}}dE = a_3[\log_e(E/\delta) + b_3\delta/E]_{78.7\delta}^{E_0} \quad (19)$$

Appendix B—Integration for Concentric Spheres

The integral in equation 15 must be separated into parts corresponding to the ranges in which the formulas 3 for α apply. Treating only the case where E_0 is in range II, the entire contribution of range I is

$$a_1\delta\int_{15\delta}^{25.8\delta} e^{b_1E/\delta}E^{-\frac{3}{2}}dE = -2a_1\delta e^{b_1E/\delta}E^{-\frac{1}{2}}\Big]_{15\delta}^{25.8\delta} + 2a_1b_1\int_{15\delta}^{25.8\delta} e^{b_1E/\delta}E^{-\frac{1}{2}}dE$$

$$= -2a_1\delta e^{b_1E/\delta}E^{-\frac{1}{2}}\Big]_{15\delta}^{25.8\delta} + 4a_1(b_1\delta)^{\frac{1}{2}}\times\int_{\sqrt{15b_1}}^{\sqrt{25.8b_1}} e^{Z^2}dZ \quad (20)$$

where the last integral is obtained through the substitution $(b_1E/\delta) = Z^2$. Since values of this integral are available[22b] only for the range of limits 0 to 2, while the limits here are approximately 2.7 and 3.5, it is necessary to resort to a series[22] for computation.

For range II:

$$a_2\delta\int_{25.8\delta}^{E_0} (E/\delta - b_2)^2E^{-\frac{3}{2}}dE = a_2\delta^{1/2}\Big[(2/3)(E/\delta)^{3/2} - 4b_2(E/\delta)^{1/2} - 2b_2^2(\delta/E)^{1/2}\Big]_{25.8\delta}^{E_0} \quad (21)$$

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List of Symbols

In all cases electric field strengths are in kilovolts per centimeter and lengths are in centimeters.

$a_1 \ldots a_3$, $b_1 \ldots b_3$ = Empirical factors in formulas 3 for α

E = Field strength

E_c = Field strength at the cathode surface

E_0 = Breakdown gradient at inner cylinder or sphere

F = Function relating α/δ to E/δ; expressed for air by formulas 3

N = Number of electrons in an avalanche which has crossed the gap at the breakdown voltage, a function of E_0/δ expressed for air by the empirical formula 6

n = Number of electrons in an avalanche

r = Radial co-ordinate

r_0 = Radius of inner cylinder or sphere

r_1 = Radius of outer cylinder or sphere

S = Distance from cathode to anode along the avalanche path, a line of force

s = Co-ordinate of avalanche center measured from the cathode along a line of force

α = The Townsend coefficient for ionization by electron impact; the number of electrons added to an avalanche per centimeter of travel per electron already present (centimeters)$^{-1}$

γ = The probability that a positive ion striking the cathode will release an electron

δ = Relative air density; unity for 760 millimeters and 25 degrees centigrade

Picture Transmission by Submarine Cable

J. W. MILNOR
FELLOW AIEE

Synopsis: The direct transmission of pictorial matter over transatlantic submarine cable has become practical through the development of some special types of networks and amplifiers. These are required because of the rapid increase of the circuit attenuation with frequency, and in order to override certain characteristic electrical interference to which the cable is subject. A summary is presented of the fundamental theory which governs facsimile and telegraph transmission, and the methods are shown by which this is applied to meet the conditions of cable picture working.

AN efficient system for transmission of facsimile matter from London to New York by submarine cable was made available to the public in April 1939. This provides an important advantage over radio sending of pictorial subjects, in that the cable system is not subject to unpredictable variations in the transmitting medium. But while the path from sender to receiver is inherently constant with time, the cable possesses characteristics which provide some unusual problems of transmission. The measures which were adopted to insure an undistorted likeness of the original and to transmit the intelligence at a maximum rate within the limited frequency spectrum available through the cable, appear to be sufficiently unique to justify a description at some length.

This new system should not be confused with the "Bartlane" system of picture sending which was applied to cables for several years. In the Bartlane system the picture was analyzed into small unit squares, and a code character was set up corresponding to each unit. The characters were sent by means of the equipment ordinarily serving for telegraph transmission, and were decoded, usually automatically, at the receiving end. That system was inherently slow and made inefficient use of the available cable capacity as compared with the arrangement described herein.

Description of Cable Circuit

The transatlantic cable which is utilized for picture transmission, indicated in figure 1, extends from Penzance, England to a repeater point at Bay Roberts, Newfoundland and thence to Rockaway, New York. Conductors in lead covered cable complete the circuit from London, England through Bristol to Penzance, and from Rockaway to New York City. The submarine cable contains a central copper conductor which is provided with a continuous wrapping of permalloy tape for magnetic loading, and which in turn is covered with gutta percha for insulation.

For picture transmission there are inserted repeaters of the electronic type, together with suitable signal shaping networks, at each of the above named points. The repeaters replace those in part mechanical which are in service when the cable is in telegraph operation.

In figure 2 is shown the electrical loss in each portion of the circuit, plotted against frequency.

Fundamental Transmission Requirements

The usual practice in picture transmission is to make use of a carrier current in the path from sending to receiving terminals. However, any carrier arrangement is wasteful of the available frequency spectrum, and in the case of submarine cable working it was especially necessary to minimize any waste. Therefore a carrier is not used in the cable in the system under discussion; instead the currents correspond directly with the shades of the original picture, varying from black, which produces maximum negative current in the cable, through gray to white which corresponds to maximum positive current.

The transmission of a picture involves the sending and receiving of a large number of transient electrical currents. But every transient can be considered as the sum of a series of sinusoidal waves, and it is far more convenient to discuss the phenomena in terms of the ability of the system to transmit alternating current in a band of frequencies. In this case we are interested in the transmission from sender to receiver of all frequencies from near zero to about 110 cycles per second.

There is a definite upper limit of frequency which may be passed through a submarine cable. The cable, like radio, is subject to static interference, and because of the rapid increase in cable attenuation with frequency as shown in figure 2, the signal-to-noise ratio rapidly falls as the frequency is increased. In this cable the ratio becomes so low at about 110 cycles that currents at frequencies above this value tend to be lost in the interference. The receiving equipment is arranged to cut off shortly above this frequency in order to minimize as far as practicable the effects of outside interference.

It also is necessary to arrange the system so that the receiving equipment is insensitive to direct current or to alternating currents of very low frequency, otherwise it would be unworkable from time to time because of the earth potentials which affect ocean cables. Amounts of five volts or more occur al-

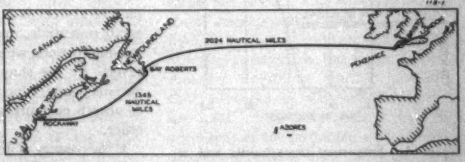

Figure 1. Route of 1926 loaded submarine cable used for picture transmission

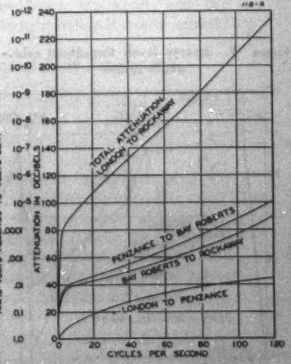

Figure 2. Attenuation of cable sections

Paper 41-18, recommended by the AIEE committee on communication and presented at the AIEE winter convention, Philadelphia, Pa., January 27-31, 1941. Manuscript submitted November 20, 1940; made available for preprinting December 2, 1940.

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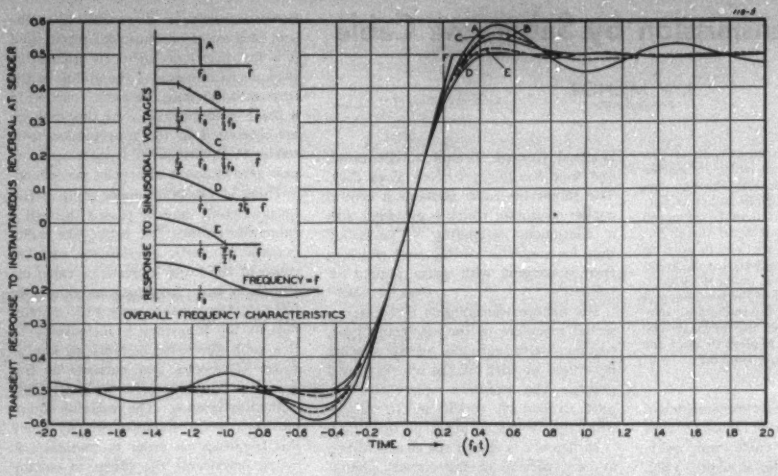

Figure 3. Arrival curves

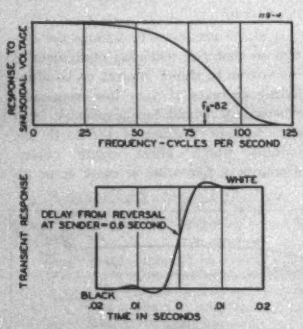

Figure 4. Frequency characteristic and arrival curve obtained over London-New York cablephoto system

most daily, and at times when abnormal conditions occur on the surface of the sun, the voltages are much higher. Values as high as 500 volts have been recorded, although such amounts occur only at long intervals. Earth potentials may be considered to be very low frequency alternating voltages, the frequency ranging from perhaps one cycle per hour to two cycles per minute. The receiving picture system is made immune to such earth potentials, except at the very occasional periods when they are unusually severe, by the shaping networks at the various points, which are arranged largely to absorb currents at frequencies of this order.

If the passage of direct currents through the cable were desirable, their transmission would in fact have been difficult because of practical considerations in the design of the amplifiers, and because of the necessity of separating from the cables the high voltage batteries used as plate supply in power amplifiers, in order to prevent the possibility of damage to cable insulation. The condensers used for the purpose have the unavoidable effect of removing most current components of the lowest frequencies.

Any arrangement of telegraph or of picture transmission in which low frequencies and direct currents are not received would be inoperable unless some arrangement were provided to compensate for the missing components of the signal. In the present case this is accomplished

Figure 5. Energy levels throughout cablephoto system

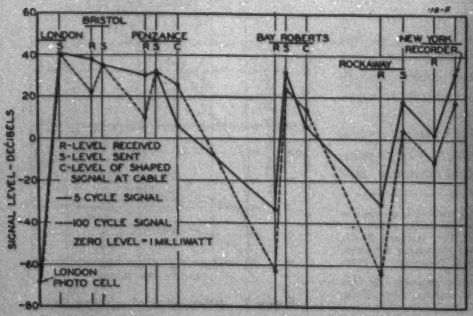

Figure 6. Cablephoto transmitter at London. Photograph sent by cable to New York

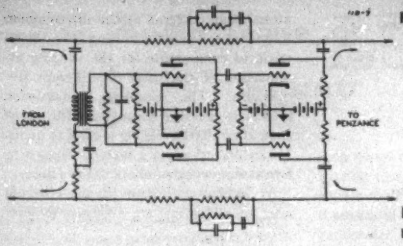

Figure 7. Repeater at Bristol

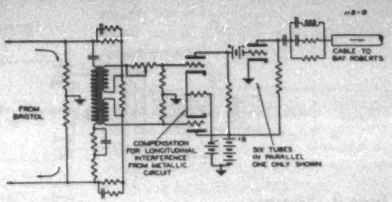
FROM BRISTOL
CABLE TO BAY ROBERTS
COMPENSATION FOR LONGITUDINAL INTERFERENCE FROM METALLIC CIRCUIT
SIX TUBES IN PARALLEL ONE ONLY SHOWN

Figure 8 (right). Repeater at Penzance

by an automatic adjustment of the received signal at the end of each scanning line in the picture. At that moment it is arranged to reduce to zero (corresponding to neutral gray in the picture) the current at the sending station. At the corresponding time there is cut into the circuit at the receiving station a set of equipment which measures the amount of current being received and automatically compensates for the current level if it departs from normal. Thus the next scanning line is started with the received level at its correct value.

In its passage through the system, the facsimile signal must be amplified sufficiently to overcome the cable attenuation at the highest frequency that is utilized, in addition to the unavoidable loss of energy in various elements of the equipment. The total available amplification from the sending photocell to the receiving lamp is approximately 420 decibels.

The shaping networks at various points perform the functions discussed in the past few paragraphs, and in addition they discriminate between different frequencies in a manner to compensate with some precision for their large difference in attenuation and phase shift in the cable. For example, a current at five cycles is reduced as much as 109 decibels, as compared with that at 100 cycles, by the shaping networks.

Theory of Signal Shaping

The combined effect of the shaping networks at all points determines the faithfulness of the final product and the efficiency of utilization of the available frequency spectrum. The problem is parallel to that encountered in telegraphy in endeavoring to transmit a maximum quantity of material within a given range of the frequency spectrum.

When a reversal from black to white occurs at the sending transmitter, the effect reaches the distant recorder in the form of an "arrival" voltage, rounded somewhat and possibly otherwise distorted from the shape of the current as sent. Each possible arrival curve corresponds to a definite "frequency characteristic" of the entire transmission system, which is the ratio of received to sent voltage plotted as a function of frequency, assuming that the transmitter has been replaced by a generator of sinusoidal currents. The choice of the frequency characteristic markedly influences the efficiency of the system.

The frequency characteristic comprises in general both an amplitude function and a phase function. An arrival curve is not received at the same instant that the reversal occurs at the transmitter; instead there is a slight delay, and that lag corresponds to a change in phase angle which is proportional to the frequency. Such a phase change is not of importance as affecting the efficiency. If such phase changes only are present the arrival curve is symmetrical. Basic theory* shows that any phase change other than in proportion to the frequency, which introduces components in the frequency characteristic in quadrature to the main component, causes the arrival curve to be nonsymmetrical. Such a phase response makes less effective use of the cable capacity.

Since the attenuation of a cable increases rapidly with frequency, and the higher frequencies are increasingly difficult to utilize, it might be expected that the preferred over-all frequency characteristic would be one which cuts off sharply at the upper end of the useful range. Investigation, however, shows that such a characteristic is associated with an arrival curve which oscillates to an objectionable extent both before and after the main reversal.

Plots of a number of symmetrical arrival curves, with their corresponding frequency characteristics, are illustrated in figure 3**. The characteristics have been so chosen (with equal area under each) that the maximum slope of each arrival curve is the same. The amount of resolution in the direction of scanning is approximately proportional to the mean frequency f_0. The effect of an abrupt cut-off of the characteristic is shown in curve A.

Entire freedom from oscillations in the arrival curve requires the use of a characteristic which with increasing frequency decreases quite gradually to zero, and which therefore is quite wasteful of cable capacity. Curve D is an example of such a characteristic. However, a desirable compromise between the efficiency of cable utilization and the appearance of the resulting picture is obtained by permitting a moderate overthrow and oscillation in the arrival curve, which is not objectionable and may be of advantage in accenting the lines of the image.

Frequency characteristics precisely like those just shown, and with the correct phase angles, could hardly be obtained through the use of equipment which it is practical to assemble, but fairly close approaches should be feasible providing that networks of sufficient complexity are used. The arrival curve and the amplitude of the frequency characteristic actually obtained over the cablephoto system are shown in figure 4. Phase angle changes, other than those proportional to frequency, are small, and the arrival curve therefore is nearly symmetrical.

Amplifying Equipment

A number of unique problems were encountered in providing the necessary amplification and signal shaping at various points along the route. The manner in which the signal level varies from point to point is indicated in figure 5.

The transmitter in London, figure 6, contains a light shutter ahead of the photocell which breaks the beam at the rate of 1,350 times per second. The output of the photocell in the form of a carrier is amplified, demodulated, again amplified and impressed upon the line in the form of a signal in which the various voltages from maximum negative to

*Submarine Cable Telegraphy, J. W. Milnor. AIEE Transactions, February, 1922. Note, equation 10 in the appendix, which served for computations of the arrival curves included herein.

**In this figure the frequency characteristics C, D, and E are portions of sine or cosine curves as shown. The characteristic F is of the form $2f_0/\pi f \sin \pi f/2f_0$.

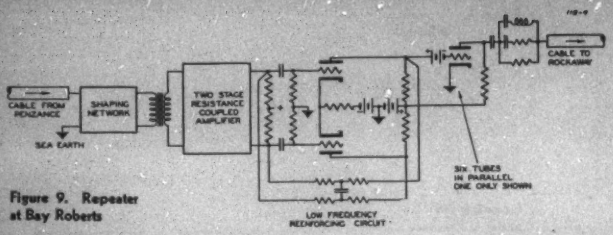

Figure 9. Repeater at Bay Roberts

maximum positive correspond to the shades from black to white. The wires which are available from London to Bristol and from Bristol to Penzance, set up as a metallic pair, are capable of handling frequencies somewhat above 120 cycles per second, but are not suitable for carrier working.

At Bristol the currents are passed through a type of repeater, figure 7, which in the interest of simplicity is arranged to amplify the higher frequency components only. The lower frequency components are by-passed around the amplifier.

At Penzance, figure 8, the currents are received from a metallic pair and after amplification are sent into a submarine cable which makes use of ground return. The metallic pair, while relatively free from interference between the wires, is subject to serious longitudinal interference. The problem of passing into a ground-return circuit the wide frequency range of the needed currents, while avoiding the longitudinal interference, is met by the use of a push-pull amplifier including a degenerating arrangement which renders it insensitive to longitudinal voltages, while amplifying the transverse signal voltages from the incoming pair.

The transformers and the condensers which were placed in circuit at certain points because of practical considerations,

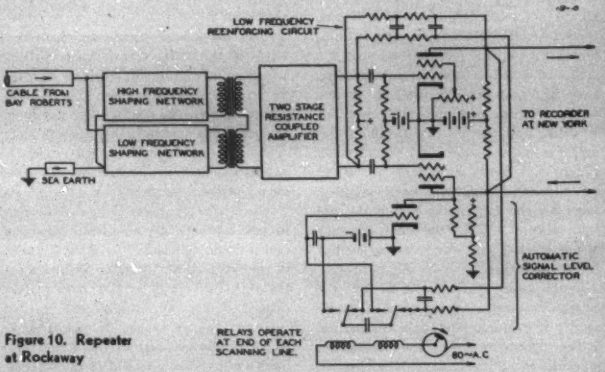
LOW FREQUENCY REENFORCING CIRCUIT
CABLE FROM BAY ROBERTS
HIGH FREQUENCY SHAPING NETWORK
LOW FREQUENCY SHAPING NETWORK
SEA EARTH
TWO STAGE RESISTANCE COUPLED AMPLIFIER
TO RECORDER AT NEW YORK
AUTOMATIC SIGNAL LEVEL CORRECTOR
RELAYS OPERATE AT END OF EACH SCANNING LINE.
60~A.C

Figure 10. Repeater at Rockaway

have the unavoidable effect of largely reducing some of the desirable frequency components in the signal, particularly those components below about 0.4 cycle per second. To correct for this loss there is inserted in the repeater at Bay Roberts, figure 9, and again in that at Rockaway, a network which through feed-back action serves to re-enforce the lowest frequencies, while having no influence upon the higher ones.

Shaping networks in addition to those just described are included at all points except at the terminals for the purpose of attenuating currents at the intermediate frequencies and controlling the phase angle to compensate for the varying attenuation of the cable at different frequencies. The complete transmission system is effective throughout the range from about 0.04 cycle per second to about 110 cycles, which is a ratio of highest to lowest frequency of about 2,750 times.

At Rockaway, figure 10, the currents after amplification are adjusted in level automatically in the manner previously described, at the end of each scanning line, in order to compensate for the absence of signal components below about 0.04 cycle per second. At that instant, because of the momentary reduction to zero of the output from London, the output of the Rockaway amplifier should also be zero. The relays in the automatic corrector are caused to vibrate rapidly at that time. If any difference in potential then exists across the amplifier, the grid of one of its tubes is adjusted quickly until the difference in potential is removed.

The output of the repeater at Rockaway is passed on to New York, and is there again amplified and impressed upon a gas-filled lamp which serves to expose the receiving photographic film.

Times Wide World

Figure 11. Trafalgar Square. Photograph transmitted by cable from London to New York

Results

Typical photographs transmitted by cable are shown in figures 6 and 11. These were transmitted at the rate of 2.2 square inches per minute, with scanning at 60 lines per inch. The resolution in the direction of scanning is especially fine, and is sufficient to warrant an increase either in the number of scanning lines per inch or a decrease in the time of transmission of a given area of picture.

The Audio Noise of Transformers

W. C. SEALEY
MEMBER AIEE

Synopsis: When transformers are installed near inhabited districts, their noise must be limited to unobjectionable values. Consequently, means of predetermining noise levels from the design constants of the transformer and means of noise reduction become necessary. It has been determined that the audio noise of transformers originates in the change in dimensions (magnetostriction) produced in the core steel by the alternating magnetic flux. The vibration caused by the change in dimensions is transmitted to the air through the tank walls. The basic noise may be increased due to the resonant vibration of mechanical parts. Theoretical relations for the sound produced have been derived. These relations are checked by tests on commercial transformers.

Introduction

WHEN power transformers are installed in locations remote from residences or other buildings used constantly by human beings, audio noise created by them is not a problem. However, as loads increase it becomes desirable to place larger transformers closer to inhabited districts. Large transformers can create sufficient noise as to make their presence in inhabited districts objectionable. In addition, the public is becoming more noise conscious and insistent on the elimination of objectionable noise of any kind.

Consequently, the calculation of the noise of a transformer from its design constants in order to predict the amount of the noise and a study of means of noise reduction becomes a practical necessity.

Origin of Noise of Transformers

Audio noise of transformers originates in the change in dimensions produced in the core steel when it is magnetized.

When iron is magnetized, its dimensions change due to the magnetization. Usually, the iron lengthens parallel to the flux lines and decreases in dimensions at right angles to the flux lines. The change in dimensions is extremely small. For example, a typical transformer punching 100 inches long will increase in length 0.0002 inches when the transformer is excited at full voltage.

Figure 1 shows percentage changes in length for typical transformer steel. Although small, the change in dimensions sets up sound waves in the manner common whenever rapid movement of a solid (in this case the steel) in contact with an elastic medium (air or oil) occurs. The intensity of the sound (in watts per square centimeter or similar units) is proportional to the square of the amplitude of vibration. When the magnetizing force is alternating as in a transformer, the sound waves issue continuously. Such is the source of noise in a transformer. Its origin is the vibration of the iron core caused by the change in dimensions commonly called magnetostriction.

Measurement of Noise*

A method of predetermining the noise of a transformer from its design is the first step in designing a quiet transformer. This requires, in turn, a satisfactory means of measuring noise and convenient units for expressing the amount of noise.

Noise can be expressed in a wide variety of ways. A fairly complete description would be a curve of watts per square centimeter versus time. It is obvious that such a curve does not lend itself to ready comparison and analysis. Recurrent sound may be expressed as the sum of its various harmonics each expressed in terms of its maximum amplitude. Such an expression is useful for sound analysis and is frequently used for this purpose in noise reduction. It may be obtained by recording the curve of intensity versus time and analyzing it into its harmonics, or by the more usual process of obtaining each harmonic separately by a harmonic analyzer.

However, such measurements do not result in the simplicity necessary for convenient general use. It is highly desirable to have a method of measurement of noise or sound intensity which can be expressed in terms of a single unit.

Such measurement is complicated by the fact that the human ear which is the final arbiter of noise has a different response for each different frequency of sound and in addition, the comparative response varies with the amplitude of the sound.

To take account of the variation in response of the ear to the various frequencies, the measurement must give weighted values to the intensities of the various frequencies. Standard curves for such weighting have been established. Using these curves as a base, the common method in use today for giving an overall expression of the amount of noise is to express it in decibels. For example, a particular sound is said to have an intensity of 60 decibels.

The decibel is really the measure of the ratio of two amounts of power. Since the human ear responds to an extremely wide range of sound intensities, the decibel offers a convenient means of expression of sound intensity. The decibel is so expressed mathematically that the sound intensity increases ten times for each ten decibels increase in sound level. Mathematically the sound level in decibels =

$$10 \log_{10} \frac{I}{I_0}$$

where I_0 is the reference intensity for the scale in watts per square centimeter or similar units and I is the measured intensity in the same units. The reference level I_0 in common use at present is 10^{-16} watts per square centimeter which at a temperature of 20 degrees centigrade and a pressure of 760 millimeters of mercury corresponds to a pressure of 0.000204 dynes per square centimeter for plane or spherical free waves. Expressed in terms of the pressure, the sound level in decibels, $\text{db} = 20 \log \frac{P}{P_0}$ where P_0 is the reference sound pressure in dynes per square

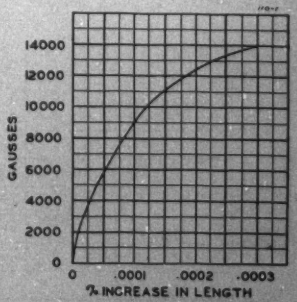

Figure 1. Typical magnetostriction curve of high-silicon transformer steel

Paper 41-10, recommended by the AIEE committee on electrical machinery and presented at the AIEE winter convention, Philadelphia, Pa., January 27-31, 1941. Manuscript submitted September 19, 1940; made available for preprinting December 19, 1940.

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* Further information can be found in the American Tentative Standards Z24.1, Z24.2, and Z24.3, and AIEE test code No. 520.

centimeter or similar units and P is the measured sound pressure in the same units. Suitable instruments have been developed for measuring the over-all sound level in decibels. Other instruments have been developed for analyzing a sound into its harmonics. At the present time these are not precision instruments in the same sense that the more common electrical measuring instruments are. However, they are sufficiently accurate to be extremely useful in sound level determination. One of the obstacles has been the difficulty of calibration so that readings with the same meter or other meters calibrated at different times will be the same.

Theoretical Variations of Sound With Weight

Based on these methods of expressing and measuring sound, theoretical relations for the noise of transformers are derived. It is general experience that the noise of a transformer varies with its size and that large transformers are usually more noisy than small transformers.

It is also well known that the noise of a given transformer increases as the applied voltage is increased. That is, the sound level of a transformer increases as the induction in the iron is increased.

According to the standards which have been established for measuring transformer noise, the sound intensity is measured one foot away from the major sound producing surface. Consequently the sound intensity measured is practically the sound intensity at the surface of the sound transmitting member.

The first relation derived is that between sound intensity and the weight of the transformer core. For transformers of similar proportions the core weight, W, is proportional to the length of the core L, raised to the third power.

Thus $W = K_1 L^3$ where K_1 is a constant

When the transformers considered have the same induction in the iron core, the noise intensity, I, at the outside of the transformer is proportional to the square of the core length because of the general law that the noise intensity is proportional to the square of the amplitude of vibration and because the change in dimensions due to magnetostriction is proportional to the core length.

Thus $I = K_2 L^2$ where K_2 is a constant

$$L = \frac{(W)^{1/3}}{(K_1)^{1/3}}$$

Substituting for L in: $I = K_2 L^2$

$$I = K_3 W^{2/3} \text{ where } K_3 = \frac{(K_2)}{(K_1)^{2/3}}$$

or the noise intensity is proportional to the weight of the core raised to the two-thirds power when the induction in the iron is constant.

Since the sound level in decibels, db by definition, equals

$$10 \log_{10} \frac{I}{I_0}; \quad \text{db} = 10 \log_{10} \frac{(K_3 W^{2/3})}{(I_0)}$$

$$\text{db} = 10 \log_{10} \frac{(K_3)}{(I_0)} + \frac{20}{3} \log_{10} W$$

Where $K_4 = 10 \log_{10} \frac{(K_3)}{(I_0)}$ = a constant when the reference intensity I_0 is constant

$$\text{db} = K_4 + \frac{20}{3} \log_{10} W$$

or the noise level in decibels is equal to a constant plus 6.67 times $\log_{10}$ (weight).

From this relation, it is evident that changing the reference level does not change the slope of the curve, but merely the value of K_4.

Theoretical Variation of Sound With Induction

The second relation derived is that between sound intensity due to magnetostriction and the maximum induction in the iron. The curve of change in length due to magnetostriction (figure 1) is obtained from tests on small samples of iron tested one sheet at a time in a device for determining the change in length due to magnetization of the sheet.

If S is the per cent increase in length due to magnetostriction, and K is a suitable factor, the sound intensity, I, for a given transformer is equal to KS^3. If the relative proportions of the different harmonics of the sound to each other remain the same with variation in S, K will be a constant. This derivation applies to all cases where K may be assumed to be constant with permissible error.

If S_0 is the per cent increase in length for reference level of induction B_0, the sound intensity, I_0, at the reference level is equal to KS_0^3.

Since the sound level in decibels, db by definition equals $10 \log_{10} \frac{I}{I_0}$;

$$\text{db} = 10 \times \log_{10} \frac{S^3}{S_0^3} = 20 \log_{10} \frac{S}{S_0}.$$

If in figure 1, the reference level is chosen as 12,000 gausses $S_0 = 0.000177$ per cent, and $\text{db} = 20 \log_{10} \frac{S}{0.000177}$.

By substituting values of S from figure 1, values for plotting curve A of figure 2 are obtained. Curve A of figure 2 shows the change in sound level in decibels, due to magnetostriction when the maximum induction in the iron changes.

Tested Variation of Sound With Induction

Curve B of figure 2 was obtained by testing with a sound level meter the sound intensity of complete commercial transformers. The values of decibels read on the meter were corrected to a reference level of 12,000 gausses by subtracting the db at 12,000 gausses from the values at other inductions. It will be noted that the agreement between curves A and B of figure 2 is very close. This is an indication of the correctness of the theoretical analysis and in addition an indication that the origin of the noise was the magnetostriction of the iron with at most a negligible quantity of noise from other sources.

If steel having different magnetostriction characteristics were used, curves similar to figure 2 for the different steel would be used for sound intensity determinations. For certain cases, accurate determination of curve A is involved but curve B can always be obtained directly from sound intensity measurements.

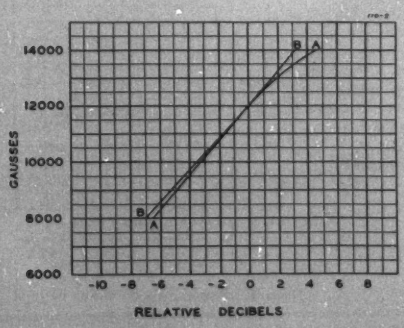

Figure 2. Variation of sound intensity with induction

Curve A—From magnetostriction tests on steel

Curve B—From sound level tests on complete transformers

Tested Variation of Sound Level With Core Weight

In order to check the correctness of the derived relation between noise in db and the core weight, a large number of sound level tests made on commercial transformer both in the shop and in the field were compared with calculated values.

Most of the tests were made at normal flux density for the transformers and in order to compare the values, they were reduced to a common flux density of 12,000 gausses. The values plotted in figure 3 are the sound intensity corrected to an induction of 12,000 gausses and the actual weight of the iron core in per cent of a common base.

The figure of 12,000 gausses to which the sound levels were corrected was chosen as being near the average induction of typical transformers. The correction was made by the use of figure 2. If W is the total weight of the core, W_1 is the weight of the part of the core considered, and its induction during the noise test was B_1, the value from figure 2 corresponding to B_1 was F_1, and the correction in db due to the part of the core considered was C_1, then $C_1=\left(\frac{(F_1W_1)}{W}\right)$. These corrections are obtained for the various parts of the core and added algebraically. In order to correct the sound reading obtained by test to the sound level corresponding to 12,000 gausses for plotting, the correction is subtracted algebraically from the test value. This method of making the corrections, is of course, an approximation but for the small variation in flux density which existed, the error introduced is negligible.

For example, a transformer has a tested noise level of 62 decibels. The weight of the core steel, W_1, is 2,000 pounds; B_1 its induction is 12,500 gausses; the weight, W_2, of the yoke steel is 3,000 pounds, its induction B_2 is 11,000 gausses. From figure 2, F_1 on curve A corresponding to 12,000 gausses is 1.0, F_2 corresponding to 11,000 gausses is -1.7.

$$C_1=\frac{F_1W_1}{W}=1.0\times\frac{2,000}{5,000}=0.4$$

$$C_2=\frac{F_2W_2}{W}=1.7\times\frac{3,000}{5,000}=-1.0$$

$$C_1+C_2=0.4-1.0=-0.6$$

The sound level of the transformer corrected to 12,000 gausses is $62-(-0.6)=62.6$ decibels.

This is the value which would be plotted in figure 3. Values obtained in this manner were plotted and the curves of figure 3 were obtained.

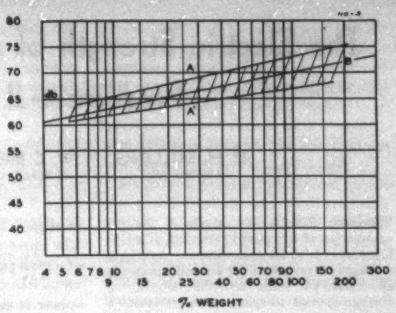

Figure 3. Variation of sound intensity with weight of core

Band A—A' indicates test values

Curve B—Theoretical curve

To obtain quantitative results from the data given for a particular transformer, the procedure is to obtain the decibel value for the transformer from figure 3 corresponding to the total weight. This is the decibels of the transformer at one foot provided all the iron were at an induction of 12,000 gausses. If the induction is at some other value, a correction for induction is made using figure 3.

EXAMPLE

A transformer with the following characteristics is assumed:

Core weight.....80 per cent of the base weight
Yoke weight.....50 per cent of the base weight
Total core weight...80 per cent of the base weight
Core induction.....12,800 gausses
Yoke induction.....11,500 gausses

The decibels corresponding to 80 per cent of the base weight on figure 3 is 69.3. From figure 2, curve A, the corrective decibels for the core =

$$\frac{30}{80}\times1.6=0.6$$

The corrective decibels for the yoke = $50/80\times-0.9=-0.56$

The corrected decibels = $69.3+0.6-0.56=69.34$ decibels

The tested values as corrected for induction are shown by the shaded area between the lines A and A'. The straight line B is drawn through the approximate center of the band with a slope so that the sound intensity varies as the two-thirds power of the core weight. The slope of this line is the same as the slope of the shaded area within the limits of experimental error.

The weights in figure 3 are given as a percentage of an arbitrarily chosen base weight. The same curve can be used for other proportions or forms of construction after the correct base weight has been determined experimentally. The band width of the curves of figure 3 is due partly to variation in the magnetostriction of the steel itself. Some of the high points outside the band were probably due to resonance phenomena involving mechanical vibration of some part of the transformer.

Measurements on identical transformers extended over a large part of the band width. Physical proportions of the transformer also affect this sound level.

It was found that radiators had little effect on the sound level when the sound level was measured at one foot from the major sound producing surface in accordance with the latest standards. This is not wholly unexpected because the sound travels through oil and metal with little attenuation, and the sound wave transmitted is extremely complex.

In general, transformers with higher exciting currents, compared with identical transformers produced higher sound levels, but additional investigation is required before general conclusions on this subject can be offered with confidence.

Reduction of Noise

The reduction of the sound level of transformers is most effectively secured by reducing the induction in the iron. To produce quiet transformers, it is necessary that parts be so constructed that reasonant vibration is negligible. No successful method of reducing the transmission of sound to the air has been developed so far.

Generally most of the objectionable sound is borne by the air. In cases where sound is conducted through the supports, sound isolating devices may be used but the solution is difficult owing to the large low frequency components of the sound.

In the future, noise reduction through steel of lower magnetostriction may be expected.

The most variable quantity at present is the magnetostriction inherent in the

The Electric Strength of Air at High Pressure—II

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Synopsis: Results are given of an investigation of the electric strength of air at pressures up to 21 atmospheres. Sparking voltages are presented for air under pressure as measured with 60-cycle alternating voltage applied to sphere gaps. Deviation from the linear pressure-voltage relation that exists at low pressures is discussed, and certain characteristics of sparking in compressed air are noted.

A STUDY of the electric strength of air under pressure was reported three years ago.[1] Because of increased interest in the subject this study has been extended, and parts of the work have been repeated with a higher degree of accuracy. Data thus obtained are of interest in the design of air-blast circuit-breakers and other types of compressed-air switches, gas-insulated transformers, power cables operating under pressure, gas-filled radio transmitting condensers, etc.

The present paper presents data relating to sparking between spherical electrodes in air, the air pressure ranging from 1 to 21 atmospheres (0 to 300 pounds per square inch gauge pressure). Results obtained with spherical electrodes may be applied with reasonable accuracy to any spark gap in which the electric field is substantially uniform. The results of this investigation are therefore applicable to sparking between the parallel plates of condensers, electrostatic shields of high-voltage apparatus, and other smooth surfaces. Breakdown between points, and at sharp edges, and between small wires, is discussed in the earlier paper.[1]

Apparatus

The spherical electrodes of the test gap, mounted in their supporting framework, are shown in figure 1. The spheres shown are approximately 20 millimeters or slightly less than one inch in diameter. The upper sphere is supported by means of a glass plate which insulates it from the metal framework. The stem of the upper sphere is electrically connected, through a spring, to the metal rod at the axis of the two glass cones near the top of the picture. These cones, clamped back-to-back, constitute the high-voltage bushing for the pressure tank in which testing is done. The axial rod through the cones serves as the high-voltage lead into the tank, and a connecting wire from the top of the rod to the high-voltage transformer may be seen in the picture. The heavy metal disk between the glass cones becomes the head of the pressure cylinder when the apparatus is assembled.

The lower sphere is adjustable vertically by means of a micrometer mechanism. The sphere may be raised or lowered without rotation. Springs are provided to prevent error due to backlash in the screw or bearings. To adjust the gap between spheres to its desired value the lower sphere is raised until it touches the upper sphere. Contact is indicated by a neon glow lamp that is connected in series with the gap while making this adjustment. The lower sphere is then lowered to its proper position as indicated by the micrometer calibration. Micrometer settings are read to 0.0001 inch.

The supporting framework for the gap is quite rigid. It is subjected to no stress other than its own weight, and the gap length is adjusted in the same position in which electrical testing is done. In particular, the supporting framework is so designed that changes of pressure of the gas do not change the length of the spark gap, as would occur if the spheres were supported from opposite ends of the tank. Temperature changes are not large, and since all major parts of the supporting framework are of the same material (steel) the gap length is not appreciably affected by expansion or contraction.

Dimensions and clearances are such that the gap is essentially a standard sphere spark gap as defined by AIEE standards.

For testing in gases other than air at atmospheric pressure the assembly shown in figure 1 is inserted in a pressure chamber as shown in figure 2. The cylinder, a 29-inch length of 10-inch steel oil well casing, is closed at top and bottom by heads of cast steel that are clamped together by 12 bolts as shown. Provision is made to admit gas to the test chamber through a pipe at the top, and two electric circuits other than the high-voltage circuit are led into the chamber by means of spark plugs. One of these circuits is used for a lamp to illuminate the interior of the chamber, and the second serves to operate a fan, to supply a source of ultraviolet radiation, and for other purposes as required. A shaft carried through a stuffing-box in the upper head allows adjustments of the spark-gap length to be made while the apparatus is assembled and under pressure. There are two small glass windows in the wall of the chamber.

High voltage is supplied to the test gap within the pressure chamber from either of two transformers, one rated 110 to 33,000 volts, 15 kva, and the other 220 to 300,000 volts, 300 kva. The latter transformer is equipped with a tertiary voltmeter winding, which is used for voltage measurement. When the 33 kv transformer is used, voltage is measured across the primary winding and the output voltage is obtained by means of the transformer turn ratio. A crest voltmeter is

Paper 41-21, recommended by the AIEE committee on basic sciences and presented at the AIEE winter convention, Philadelphia, Pa., January 27-31, 1941. Manuscript submitted November 6, 1940; made available for preprinting December 3, 1940.

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The authors wish to acknowledge the co-operation of the International Telephone and Telegraph Company in making possible the research leading to this paper.

1. For all numbered references, see list at end of paper.

steel. Consequently noise can be reduced by proper selection of the steel.

Conclusions

1. Transformer noise originates principally in the magnetostriction of the core iron.

2. Transformer noise can be calculated from the design constants using as a base magnetostriction tests of the core iron and the other relations given.

3. The most effective methods of reducing basic transformer noise are by reducing the induction in the iron or by reducing the magnetostriction of the iron.

4. The sound intensity produced by similar transformers with the same induction in the core, varies as the two-thirds power of the weight.

5. The sound intensity produced by a transformer with core iron having normal magnetostriction varies as the square of the magnetostriction. This relation can be used to compare the sound intensities produced at various inductions or to compare the sound levels of various core steels.

used for all measurements to eliminate error resulting from nonsinusoidal wave form. The over-all accuracy of voltage measurement was checked by comparison of measured values of sparking voltage between 20-millimeter spheres with AIEE standard values; the difference was less than 0.5 kv up to a reading of 40 kv, the highest voltage compared.

Resistance is used in the high-voltage connection to limit current in the test gap to one-half ampere. When sparking occurs the flow of current is interrupted at the end of the first quarter-cycle of 60-cycle current by a high-speed circuit breaker in the transformer primary circuit.

Voltage is continuously adjustable over the entire range of the transformers by means of a tap-changing transformer and an induction-type voltage regulator in the transformer primary circuit. During certain tests the transformer power is supplied from a synchronous sine-wave motor-generator set; in this case it is possible to adjust voltage by changing the generator field current as well as by means of the transformer and regulator.

Procedure

A generally uniform method of testing for the sparking voltage was followed.

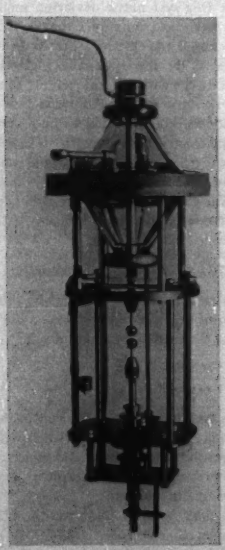

Figure 1. The sphere spark gap and supporting framework

The spheres between which sparking was to take place were mounted in the micrometer head within the pressure chamber after having been cleaned and polished. Various methods of polishing were used,

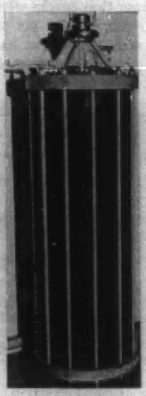

Figure 2. The test chamber containing air under pressure

and no difference was found between polishing with rouge or metal polish, by hand or by motor-driven buffing wheel. In one case a motor-driven wire brush was used on steel spheres, and although it altered the appearance from a mirror surface to a matte surface it had no effect on the electrical behavior. The presence of an oil film on the spheres made no apparent difference in sparking voltage; however it is difficult to be sure that in any case the spheres were entirely free from oil because of the probability of oil being carried into the test chamber from either an air compressor or a storage cylinder.

When an air compressor was used the air was cooled and filtered before being admitted to the test chamber. Despite the filtering, particles of oil of extremely small size were carried into the test chamber. Although the presence of the resulting haze of oil particles within the chamber had no noticeable effect on the sparking voltage, its presence resulted in a black oily deposit on the sphere surfaces after continued sparking. This was avoided by compressing the air several hours before it was used, thereby allowing the oil particles to settle out; when this procedure was followed the compressed air was perfectly clear and free from haze.

Before measuring sparking voltage the gap was adjusted to the desired length. A zero setting of the micrometer was obtained by means of a neon glow lamp, as described above. The micrometer setting was read when the lamp lighted as the spheres were being brought together and when it went out as they were separated. The difference between the two readings was normally less than 0.0001 inch.

Sixty-cycle voltage was applied to the gap, and the voltage was raised gradually until a spark occurred. The time required to raise voltage to sparking value varied from a few seconds to about half a minute, and sometimes was extended over several minutes. In some cases the speed of application of voltage was an important factor, as will be discussed.

At each particular spacing and pressure a number of readings of sparking voltage were measured and recorded. The number of readings depended upon circumstances, and particularly upon the uniformity of the measurements. If the first eight or ten sparks were at substantially the same voltage (within two or three per cent) they were considered satisfactory, but if there were radical variations the test was continued until 20, or 40, or as many as 100 sparking voltages were recorded. Either the pressure or the spacing was then changed and another series of readings was made.

Several series of tests were made with a quartz-tube mercury-arc lamp so located within the pressure chamber that its light fell on the spheres and passed through the gap between the spheres. It is impossible to say that its presence made any significant difference in the results, either in the value of voltage or in consistency of results. Use of the lamp was not continued.

Interpretation of Data

An *average* of the several voltage readings at any given spacing and pressure is not adequate to represent the results. There is apparent in much of the data a distinct trend:[4] the first sparking voltages are low and succeeding ones are higher in such a way that they appear to approach a limit. After four or five sparking voltages have been measured in rapid succession (less than a minute apart) the value of sparking voltage becomes stabilized. There is frequently a gradual rise of ten per cent or more in sparking voltage from the first spark to the fourth or fifth, while random variations of sparking voltage thereafter are not likely to vary more than one or two per cent from the trend value. If the series of sparking measurements is interrupted for five or ten minutes, however,

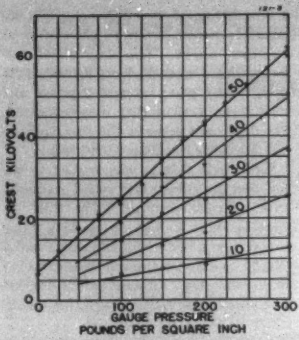

Figure 3. Sparking in air between brass spheres. Spark gap length as noted on curves in thousandths of an inch

and is then recommenced, it is probable that the first few sparks after interruption will occur at slightly reduced voltage and the stabilized value will have to be re-established. Occasionally, also, there is a break from the stabilized sparking voltage for no apparent reason; a spark will occur several per cent below the trend voltage, and successive sparks will be consecutively higher until the stabilized value is again reached.

An upward trend at the beginning of a series of sparks was found in most voltage measurements in which the voltage was greater than about 30 kv; that is, in case of either high pressure or relatively long spark gap. There was no such trend observed at atmospheric pressure, or in most measurements below about 20 kv. Under no circumstances was there any appearance of a downward trend; the voltage readings were either quite consistent or else the erratic readings were below the stabilized value. The amount of variation between the stabilized value of voltage and the lowest sparking voltages was of the order of magnitude of ten per cent.

The stabilized value of voltage is reproducible from time to time; an average voltage value, on the other hand, cannot readily be repeated and is not particularly significant because it depends on the number of measurements at a given setting of the gap and on the history of sparking of the gap. Therefore the stabilized value of voltage has been accepted as the best value to use in representing test results in this paper. It must be recognized that a reasonable engineering value of sparking voltage is about ten per cent below the values here given because of the likelihood of occasional sparks at voltages below the stabilized value.

To a slight extent the sparking voltage at high pressure was dependent upon time of application of voltage. The stable trend value was found by raising voltage at such a rate that sparks were produced at the rate of one or two per minute. If, after the stable condition had been established, voltage two or three per cent

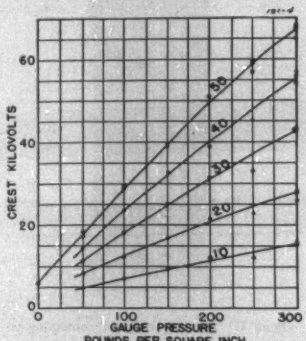

Figure 4. Sparking in air between steel spheres. Spark gap length as noted on curves in thousandths of an inch

lower than the stable sparking value was applied continuously, sparking would usually occur after some time. The time that elapsed before sparking in such a case might be from a few seconds to ten minutes. If the applied voltage was as much as five per cent below the trend value, sparking might be delayed 30 minutes. Applied voltages ten per cent or more below the trend value did not produce sparking regardless of time. To insure steady voltage supply for these tests, power was taken from a motor-generator set.

It is believed that the rising trend of sparking voltage and the time lag of sparking are associated phenomena, for they appeared under the same conditions.

Results

Results are shown in figures 3 and 4. Each indicated point represents a stabilized value determined from a series of individual voltage readings. About 2,000 individual readings of sparking voltage are represented by these sets of curves.

The data of figure 4 may be presented in another form which is more compact, although less convenient for reference. This is done by plotting the sparking voltage as a function of the product of the independent variables, pressure, and spacing between electrodes. This product may be designated PS; the pressure P is most conveniently measured in atmospheres, and the spacing between electrodes, S, may be in inches.

According to the law for sparking commonly known as Paschen's law[2,4,5], voltage at breakdown should be a function of the product PS. Numerically, Paschen's law may be expressed[3] in the above units as

$$V = 75.4PS + 1.7 \text{ kilovolts} \quad (1)$$

If Paschen's law could be extrapolated from the low pressure range, below one atmosphere, for which it was determined, to cover the many-times greater range up to 21 atmospheres, the experimental points from figure 3 should all lie on a single straight line when plotted against the product PS. That this is approximately true may be seen in figure 5, in which all experimental points could be represented by a single straight line with an error not exceeding ten per cent. There is, however, a consistent deviation that corresponds to the drooping curvature of the lines of figure 3, and sparking voltages at high pressure are lower than sparking voltages for the same value of PS at low pressure.

In earlier papers[1] it has been suggested that this systematic deviation might result from field emission; that is, it might be caused by electrons drawn from the cathode by the extremely high electric field at the cathode surface. If this is so the deviation from Paschen's law could reasonably be expected to be a function of the electric field strength.[1] Inspection of figure 5 suggests the following modified expression for sparking voltage, in which V/S is the electric field strength between electrodes, and a is a coefficient to be determined from the data:

$$V = 76.0PS(1 - aV/S) + 1.7 \text{ kilovolts} \quad (2)$$

Solving for sparking voltage, discarding a term of negligible importance, and evaluating the coefficient a, one obtains:

$$V = \frac{76.0PS}{1 + 0.009P} + 1.7 \text{ kilovolts} \quad (3)$$

The coefficient has here been evaluated to make equation 3 agree with experimental results obtained with *brass* electrodes. The pressure P is in atmospheres and the spacing S in inches.

It may be seen that results obtained with steel electrodes (figure 4) differ slightly from results with brass electrodes (figure 3). Sparking voltages at pressures less than about 50 pounds per square

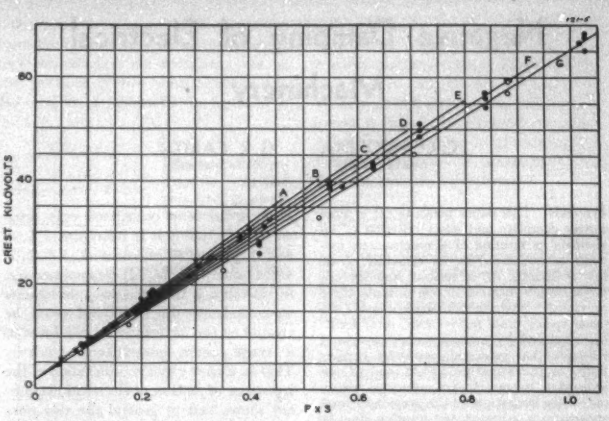

Figure 5. Sparking in air between brass spheres

P, absolute air pressure in atmospheres; *S*, spark gap length in inches. Points shown are experimental, lines are computed from equation 3

Line *A* and points marked ⊙ are for 0 pounds per square inch pressure

Line *B* and points marked ⊕ are for 50 pounds per square inch pressure

Line *C* and points marked ⊙ are for 100 pounds per square inch pressure

Line *D* and points marked ⊖ are for 150 pounds per square inch pressure

Line *E* and points marked ● are for 200 pounds per square inch pressure

Line *F* and points marked ○ are for 250 pounds per square inch pressure

Line *G* and points marked ⊗ are for 300 pounds per square inch pressure

inch are the same for steel and brass, and both agree with Paschen's law. At higher pressures the deviation from Paschen's law is greater for steel than for brass. If the deviation is assumed to be a result of field emission, it is not surprising that it should be different with different electrode materials. A difference between sparking voltage with iron and copper electrodes was noted in an earlier paper by one of the authors;[1] although it was not at that time known to be significant, it now appears comparable to the difference between steel and brass shown by figures 3 and 4.

Values of sparking voltage were measured between aluminum spheres, also. Results using aluminum electrodes in air were inclined to be erratic, some sparking voltages being as high as the values obtained with brass spheres while others were lower than results with steel. Repeated sparking between aluminum spheres in air tended to reduce the sparking voltage, the inference being that a chemical change of the electrode surfaces was taking place. (Aluminum electrodes give consistent results, comparable with brass electrodes, when used in nitrogen.)

To describe results obtained with *steel* electrodes an expression of the form of equation 3 may be used:

$$V = \frac{76.0PS}{1+0.019P} + 1.7 \text{ kilovolts} \qquad (4)$$

The coefficient in the denominator is here adjusted to give as good agreement as possible with the data of figure 4; agreement is within about ten per cent.

Although this expression for steel electrodes was derived to fit the experimental results obtained by the authors, it gives excellent agreement with sparking voltages measured by A. H. Howell.[5] Howell's electrodes were "turned from ordinary cold rolled steel." His results, although obtained with direct current from a Van de Graaff generator, appear to extend the range of equation 4 to pressures as high as 600 pounds per square inch and values of the product *PS* as great as ten.

Equation 4 also gives reasonably good agreement with results obtained by R. C. Buehl[6] with 60-cycle alternating voltage in nitrogen up to pressures of 140 atmospheres (2,060 pounds per square inch) and *PS* of seven. Agreement is within ten per cent for most of Buehl's data.

It is, furthermore, evident that Paschen's law may be considered a special case of equations 3 or 4 that applies with good accuracy when the air pressure is below about five atmospheres. Since Paschen's law has been experimentally substantiated for values of *PS* as low as 0.05 for pressures below atmospheric, it follows that equations 3 and 4 are accurate in that region also.

These considerations indicate the useful range of application of equations 3 and 4.

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See references 1 and 5 for complete bibliography.

Negative Damping of Electrical Machinery

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Synopsis: This paper presents (1) a more nearly complete and exact criterion of instability or hunting of a synchronous machine as influenced by its armature or tie line resistance, (2) a general stability criterion which includes in one formula three previously separately treated cases: the usual steady state power limit, rotor hunting produced by armature resistance, and self-excitation produced by series capacitance in the armature circuit, and (3) an indication, by means of a numerical example, of the limitations of the previously used approximate criterion for hunting due to armature resistance.

IN PREVIOUS treatments, hunting, self-excitation, and loss of synchronism have been considered only separately, neglecting their mutual interactions. The present paper, on the other hand, considers their mutual effects and thus provides a general analysis by reference to which the limitations and proper fields of application of the approximate formulas may be found. Application of the complete criterion given is however rather laborious, and it is not suggested for general use in place of the approximate forms.

Introduction

When synchronous machines are tied together through impedances having rather high resistance components, and when there is insufficient rotor damping, the machines tend to hunt. Also, when a machine is connected to a capacitance load or to a system through a series capacitor there is exhibited under certain conditions a tendency to self-excite. Both of these phenomena have been treated extensively in electrical engineering literature, and the conditions under which one or the other form of operation is to be expected are reasonably well known. However, the two phenomena have so far been considered only separately, e.g., the first in references 1, 2, 3, and the second in references 3, 4, 5, 6, 7, among many others. It was pointed out in reference 3 that the two phenomena were basically the same and could be treated as two aspects or special cases of a single, more general characteristic. That is, a more exact consideration of the equations of motion of electrical machinery shows that in general the two phenomena are mutually dependent and in fact inseparable, and that it is only because of the relatively large differences in the orders of magnitudes of the principal controlling features of each that they can be approximately separated. Since all previous treatments have considered them separately and have consequently neglected their mutual interactions, it was felt that an investigation should be made to find out just what these interactions might be. The results of such an investigation, comprising a quantitative study of the complete equations of motion of a simple electromechanical system, are presented in this paper.

Paper 41-12, recommended by the AIEE committees on power transmission and distribution, and electrical machinery, and presented at the AIEE winter convention, Philadelphia, Pa., January 27-31, 1941. Manuscript submitted October 11, 1940; made available for preprinting November 26, 1940.

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1. For all numbered references, see list at end of paper.

Preliminary Considerations

Before proceeding to the combining of self-excitation and hunting into a single form (here called negative damping), the simpler case of a system which can show only hunting was first studied, since it has been found that the behavior of this system according to the equations used here is somewhat different from that according to the approximate criteria previously given.[1]

A single synchronous machine with only one rotor winding, connected to an infinite bus, may become unstable at small generator angles or at any motor angle if the armature resistance is too high, and at large generator angles if the armature resistance is too low. Both concepts are well known, but the latter may be amplified by pointing out that at large generator angles and high resistances the system, although stable, has only a negligible synchronizing torque and load capacity.

Figures 1 and 2 show the results of stability calculations made for this case. The regions of stable operation were determined by the application of Routh's[11] stability criterion to equation 6 of the appendix. Figure 1 is for comparatively low values of armature resistance; in this figure, the solid line represents the stability limit for unit field excitation, the dashed line that for one and a half times unit excitation. For comparison, the hunting criterion $r \leqq x_q \tan \delta$, of reference 1, is also shown, as a dot-and-dash line for generator angles.

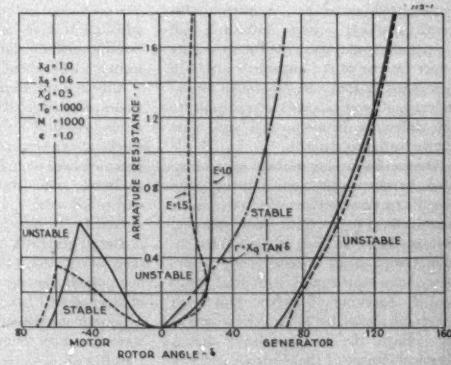

Figure 1. Synchronous machine connected to infinite bus—stability limits—effect of armature resistance r and field excitation E

It is seen that the approximate criterion is optimistic for small angles and pessimistic for larger generator angles; for the larger motor angles (from about 30 degrees to the steady state boundary) the approximate criterion $r = x_q \tan \delta$ agrees fairly closely with the more nearly exact criterion used here. At light loads figure 1 indicates that $r \leqq x_d' \tan \delta$ would be a

better criterion of stability than $r \leqq x_q \tan \delta$, at least for the value of field time constant $T_0 = 1{,}000$ studied. The more nearly exact criterion shows no instability due to high armature resistance for generator angles of more than about 30 degrees. This is not in conflict with experience, since those cases of hunting which have actually been encountered have usually occurred only at light load. Another check is obtained by noting that the amount of armature resistance required to produce negative damping at light loads decreases as the field excitation is increased, which is consistent with the observation that the severity of hunting is usually increased by increased excitation. The outer boundaries of figure 1 are found to check the steady state stability limits determined by the usual steady state power-angle relations.[12]

Figure 2 is of only theoretical interest, as the resistances involved are so high that the machine armature is practically open circuited.

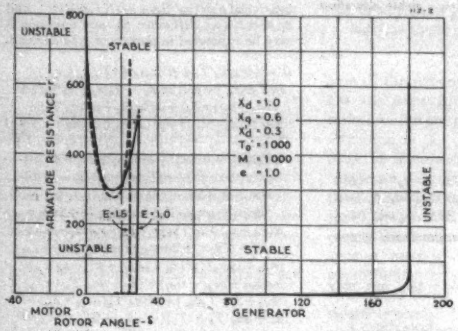

Figure 2. Synchronous machine connected to infinite bus—stability limits—effect of armature resistance r and field excitation E at high values of r

Negative Damping With Series Capacitors

Figure 3 shows some of the results of stability calculations made for the general case of a synchronous machine connected to a bus through a series capacitor. Equation 4 of the appendix gives the equation for this case. In a general way the correspondence of this stability boundary to those which would be obtained by the previous approximate methods is that first, the left hand rising portion of the curve corresponds roughly to the lower portion of the curve for $M = \infty$ of figure 1, reference 5, and second, the right hand decreasing portion corresponds to the boundary which would be found by application of the approximate criterion for hunting if the capacitive reactance x_c is subtracted from the quadrature axis reactance x_q to form an effective net reactance. As in the previous section, the criterion $r \leqq (x_d' - x_c) \tan \delta$ (shown in the figure by a dashed line) forms a better, in fact a rather good, criterion.

Figure 3 indicates that instability may occur if the resistance is too small and if the resistance is too large. An amortisseur on the machine rotor will increase the maximum allowable armature resistance so much as practically to remove any upper (right hand in figure 3) boundary. On the other hand the allowable minimum resistance will also be increased, as indicated by figure 4. Figure 4 has been calculated by the equations of reference 5, and may be compared to figure 1, reference 5, to show the effect of the amortisseur. The fact that an amortisseur does not tend to suppress the negative damping introduced by series capacitance need not be alarming however, as figure 5 shows that resistance in shunt with the capacitor is still effective in preventing the instability, just as was found in reference 3, figure 18. Figure 5 was calculated from equation 1*d* of reference 3, using an extension of equations 2*d* and 3*d* to include the amortisseur.[10]

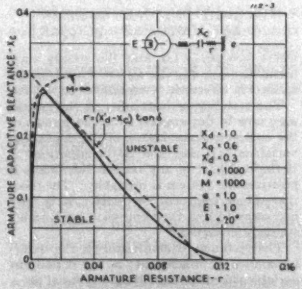

Figure 3. Synchronous machine connected to infinite bus through armature series capacitance—stability limits at rotor angle δ = 20 degrees

Conclusions

1. A more complete and exact criterion of instability of a synchronous machine as influenced by armature resistance has been derived by application of Routh's test to the system performance equations.

2. A general criterion of instability has been derived which includes three previously separately treated cases: the normal steady state power limit, rotor hunting produced by armature resistance, and self-excitation produced by series capacitance in the armature circuit.

3. The limitations of the previously used approximate criterion for hunting due to armature resistance have been determined.

4. The effect on the stability limit of series capacitance in the armature circuit has been studied by the more complete criterion and shown to agree fairly well with the approximate criteria for appropriate limiting conditions.

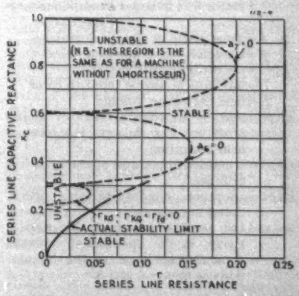

Figure 4. Negative damping of synchronous machines with series capacitors—effect of amortisseur. Series resistance required for stable operation

$x_d = 1.0$ $\quad x_d' = 0.3$ $\quad x_d'' = 0.218$
$r_{kd} = 0.02$ $\quad T_0' = 1{,}000,\ \omega = 1.0,\ \alpha = 0$
$x_q = 0.6$ $\quad x_q'' = 0.311$ $\quad r_{kq} = 0.04$
($a_7 = 0$, $a_8 = 0$, etc., are approximate criteria)

Appendix

Nomenclature

r = armature circuit resistance
δ = angle between rotor axis and axis of stator voltage

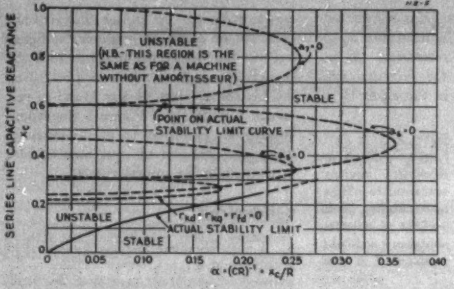

Figure 5. Negative damping of synchronous machines with series capacitors—effect of amortisseur. Shunt resistance required for stable operation

x_d = direct axis synchronous reactance
x_q = quadrature axis synchronous reactance
x_d' = direct axis transient reactance
x_d'' = direct axis subtransient reactance
x_q'' = quadrature axis subtransient reactance
T_0 = field open circuit time constant
x_c = armature circuit capacitive reactance
R = resistance in parallel with x_c
$\alpha = x_c/R$
M = rotor inertia factor in radians
e = stator voltage
i = stator current
ψ = stator flux linkages
(subscripts d and q indicate direct and quadrature axis components, respectively)
θ = rotor angle in electrical radians
p = time derivative operator $= d/dt$
$(p\theta) = \omega$ = rotor angular velocity
T = mechanical torque input to rotor
E = field excitation voltage
$G(p)$ = mutual impedance operator giving armature flux linkages in terms of field excitation
$z_d(p)$ = armature direct axis operational impedance
$z_q(p)$ = armature quadrature axis operational impedance
a_7, a_8 = the coefficients of p^8, p^7, respectively, in the operational common denominators used in the calculations of figures 4 and 5

Analysis

In this appendix the equations of a synchronous or induction machine with a capacitor and resistor in parallel in the armature circuit are extended to include the effect of rotor inertia during small changes (e.g., oscillations) of rotor speed. The fundamental equations for this case have been derived in references 5, 8, and 9, and are:

$$\left.\begin{aligned}&(p+\alpha)[e_d-p\psi_d+ri_d+\psi_q(p\theta)]+x_ci_q-\\&\qquad(p\theta)[e_q-p\psi_q+ri_q-\psi_d(p\theta)]=0\\&(p+\alpha)[e_q-p\psi_q+ri_q-\psi_d(p\theta)]+x_ci_d+\\&\qquad(p\theta)[e_d-p\psi_d+ri_d+\psi_q(p\theta)]=0\\&T=\psi_di_q-\psi_qi_d+Mp^2\theta\end{aligned}\right\}\quad(1)$$

where

$e_d = e\sin\delta \qquad \psi_d = G(p)E - x_d(p)i_d$
$e_q = e\cos\delta \qquad \psi_q = -x_q(p)i_q$

and the other symbols are as defined in reference 8 and in the nomenclature. From equations 1, by taking small changes

$x_d = 1.0 \qquad x_d' = 0.3 \qquad x_d'' = 0.218$
$r_{kd} = 0.02 \qquad T_0 = 1{,}000,\ \omega = 1.0,\ r = 0$
$x_q = 0.6 \qquad x_q'' = 0.311 \qquad r_{kq} = 0.04$
$(\alpha_7 = 0,\ \alpha_8 = 0$, etc., are approximate criteria)

in e, E, i_d, i_q, and $\delta(\Delta\theta = \Delta\delta)$, one may obtain:

$$\left.\begin{aligned}&[(p+\alpha)(px_d(p)+r)+x_c-\omega^2x_d(p)]\times\\&\Delta i_d-[(p+\alpha)\omega x_q(p)+\omega(px_q(p)+r)]\times\\&\Delta i_q+\{[(p+\alpha)\psi_{q0}+2\omega\psi_{d0}-e_{q0}-ri_{q0}]\times\\&p+(p+\alpha)e_{q0}+\omega e_{d0}\}\Delta\delta=[-(p+\alpha)\times\\&\sin\delta_0+\omega_0\cos\delta_0]\Delta e+[(p+\alpha)p-\omega_0^2]\times\\&\qquad G(p)\,\Delta E\\&[(p+\alpha)\omega x_d(p)+\omega(px_d(p)+r)]\Delta i_d+\\&[(p+\alpha)(px_q(p)+r)+x_c-\omega^2x_q(p)]\Delta i_q+\\&\{[-(p+\alpha)\psi_{d0}+2\omega\psi_{q0}+e_{d0}+ri_{d0}]p-\\&(p+\alpha)e_{d0}+\omega e_{q0}\}\Delta\delta=[-(p+\alpha)\cos\delta_0-\\&\omega_0\sin\delta_0]\Delta e+(2p+\alpha)\omega_0G(p)\,\Delta E\\&-[\psi_{q0}+i_{q0}x_d(p)]\Delta i_d+[\psi_{d0}+i_{d0}x_q(p)]\times\\&\qquad\Delta i_q+Mp^2\Delta\delta=\Delta T-i_{q0}G(p)\,\Delta E\end{aligned}\right\}\quad(2)$$

where $\omega_0 = (p\theta)_0 = 1.0$, and the steady state quantities ψ_{d0}, ψ_{q0}, i_{d0}, i_{q0} are found as described in reference 5, equations 32, 33, 34.

The stability or instability of the system may now be determined from the p roots of the common denominator of the dependent variables Δi_d, Δi_q, and $\Delta\delta$ in equations 2. If the real part of any one of these roots is positive, the system is unstable. The roots themselves need not be found; it is only necessary to test the expression by Routh's stability criterion.[11]

The common denominator is the determinant of the coefficients of the dependent variables in equations (2), and is equal to:

$$\begin{aligned}D=&\{[(p+\alpha)(px_d(p)+r)+x_c-\omega^2x_d(p)]\times\\&[(p+\alpha)(px_q(p)+r)+x_c-\omega^2x_q(p)]+\\&[(p+\alpha)\omega x_d(p)+\omega(px_q(p)+r)]\times\\&[(p+\alpha)\omega x_q(p)+\omega(px_d(p)+r)]\}Mp^3+\\&[[\{[(p+\alpha)\psi_{q0}+2\omega\psi_{d0}-e_{q0}-ri_{q0}]p+\\&(p+\alpha)e_{q0}+\omega e_{d0}\}[(p+\alpha)\omega x_d(p)+\\&\omega(px_q(p)+r)]-\{[-(p+\alpha)\psi_{d0}+\\&2\omega\psi_{q0}+e_{d0}+ri_{d0}]p-(p+\alpha)e_{d0}+\\&\omega e_{q0}\}[(p+\alpha)(px_d(p)+r)+\\&x_c-\omega^2x_d(p)]][[\psi_{d0}+i_{d0}x_q(p)]+\\&[[(p+\alpha)\omega x_q(p)+\omega(px_d(p)+r)]\times\\&\{[-(p+\alpha)\psi_{d0}+2\omega\psi_{q0}+e_{d0}+ri_{d0}]p-\\&(p+\alpha)e_{d0}+\omega e_{q0}\}]+[(p+\alpha)(px_q(p)+r)+\\&x_c-\omega^2x_q(p)]\{[(p+\alpha)\psi_{q0}+2\omega\psi_{d0}-\\&e_{q0}-ri_{q0}]p+(p+\alpha)e_{q0}+\omega_0e_{d0}\}]\times\\&[\psi_{q0}+i_{q0}x_d(p)]\quad(3)\end{aligned}$$

With $M=\infty$, equation 3 reduces to that for the previously treated case of constant rotor speed (reference 3, appendix D). Also if the machine is initially unexcited, so that $\psi_0 = i_0 = 0$, the regions of stable operation are the same as before. In the general case, however, the performance will be affected by the operating angle, machine inertia, and excitations.

For a machine with only one rotor winding, $x_d(p) = (x_d'T_0p + x_d)/(T_0p+1)$ and $x_q(p) = x_q$ (see reference 8), and equation 3 may be expanded in powers of p to become:

$$\begin{aligned}D'=&\{p^5x_qx_d'T_0+p^4[x_qx_d+rT_0(x_q+x_d')+\\&2\alpha T_0x_qx_d']+p^3[(2x_qx_d'+x_c(x_q+x_d'))T_0+\\&r(x_d+x_q+rT_0)+\alpha(2x_qx_d+\alpha x_qx_d'T_0)+\\&2\alpha rT_0(x_q+x_d')]+p^2[2x_qx_d+x_c(x_d+x_q)+\\&r(T_0(2x_c+x_q+x_d')+r)+\alpha(T_0x_c(x_q+x_d')+\\&2T_0x_qx_d'+\alpha x_dx_qT_0)+\alpha r(2x_d+2x_q+2T_0r+\\&T_0\alpha(x_q+x_d'))]+p[T_0(x_c-x_q)(x_c-x_d')+\\&r(x_d+x_q+2x_c+rT_0)+\alpha(x_c(x_d+x_q)+\\&2x_qx_d+\alpha x_dx_qT_0)+\alpha r(2x_cT_0+2r+\\&\alpha(x_d+x_q)+\alpha rT_0)]+[(x_d-x_c)(x_q-x_c)+\\&r^2+\alpha^2x_dx_q+2\alpha rx_c+(\alpha r)^2]\}M\phi^3+\\&(\psi_{d0}+i_{d0}x_q)\{p^4(x_d'T_0\psi_{d0})+p^3[-x_d'T_0\times\\&(-\alpha\psi_{d0}+2\psi_{q0}+ri_{d0})+(x_q+\alpha x_d'T_0+rT_0)\times\\&\psi_{d0}+2x_d'T_0\psi_{q0}]+p^2[x_d'T_0(\alpha e_{d0}-e_{q0})-\\&(x_d+\alpha x_d'T_0+rT_0)(-\alpha\psi_{d0}+2\psi_{q0}+ri_{d0})+\\&(\alpha x_d+r+\alpha rT_0-x_d'T_0+x_cT_0)\psi_{d0}+\\&2x_d'T_0(\alpha\psi_{q0}+2\psi_{d0}-ri_{q0})+(2x_d+rT_0+\\&\alpha x_d'T_0)\psi_{q0}]+p^1[(x_d+\alpha x_d'T_0+rT_0)(\alpha e_{d0}-\\&e_{q0})+(2x_d+rT_0+\alpha x_d'T_0)(\alpha\psi_{q0}+2\psi_{d0}-\\&ri_{q0})-(\alpha x_d+r+\alpha rT_0-x_d'T_0+x_cT_0)\times\\&(-\alpha\psi_{d0}+2\psi_{q0}+ri_{d0})+(r+\alpha x_d)\psi_{q0}+(x_c-\\&x_d+\alpha r)\psi_{d0}+2x_d'T_0(\alpha e_{q0}+e_{d0})]+p[(\alpha x_d+\\&r+\alpha rT_0-x_d'T_0+x_cT_0)(\alpha e_{d0}-e_{q0})+(2x_d+\\&rT_0+\alpha x_d'T_0)(\alpha e_{q0}+e_{d0})-(x_c-x_d+\alpha r)\times\\&(-\alpha\psi_{d0}+2\psi_{q0}+ri_{d0})+(r+\alpha x_d)\times\\&(\alpha\psi_{q0}+2\psi_{d0}-ri_{q0})]+[(x_c-x_d+\alpha r)\times\\&(\alpha e_{d0}-e_{q0})+(r+\alpha x_d)(\alpha e_{q0}+e_{d0})]\}+\\&[(\psi_{q0}T_0+i_{q0}x_d'T_0)p+(\psi_{q0}+i_{q0}x_d)]\times\\&\{p^4(\psi_{q0}x_q)+p^3[\psi_{q0}(\alpha x_q+r)+(\alpha\psi_{q0}+\\&2\psi_{d0}-ri_{q0})x_q-\psi_{d0}2x_q]+p^2[\psi_{q0}(r\alpha+\\&x_c-x_q)+(\alpha\psi_{q0}+2\psi_{d0}-ri_{q0})(\alpha x_q+r)+\\&(\alpha e_{q0}+e_{d0})x_q-\psi_{d0}(\alpha x_q+r)+(-\alpha\psi_{d0}+\\&2\psi_{q0}+ri_{d0})2x_q]+p[(\alpha\psi_{q0}+2\psi_{d0}-ri_{q0})\times\\&(r\alpha+x_c-x_q)+(\alpha e_{q0}+e_{d0})(\alpha x_q+r)+\\&(-\alpha\psi_{d0}+2\psi_{q0}+ri_{d0})(\alpha x_q+r)-\\&(\alpha e_{d0}-e_{q0})2x_q]+[(\alpha e_{q0}+e_{d0})(r\alpha+x_c-x_q)-\\&(\alpha e_{d0}-e_{q0})(\alpha x_q+r)]\}\quad(4)\end{aligned}$$

Note that the coefficient of Mp^3 in this equation is the Δ' of equation 4d, appendix D, of reference 3.

Equation 4 may be used to find the effect of rotor inertia on negative damping in the region of series capacitor applications where the machine is connected to an excited bus through a capacitor. For a capacitance load, as for transmission line capacitance, e_{d0} and e_{q0} should be taken as zero, in which case the effect of rotor oscillations on the borderline of stability is believed to be negligible, as there are no synchronizing torques.

For the special case of no armature circuit capacitance ($x_c = 0$ or $\alpha = \infty$), the performance equations 2 become

$$\left.\begin{aligned}&-(px_d(p)+r)\,\Delta i_d+\omega_0x_q(p)\,\Delta i_q-\\&\qquad(\psi_{q0}p+e_{q0})\,\Delta\delta=\sin\delta_0\,\Delta e-pG(p)\,\Delta E\\&-\omega_0x_d(p)\,\Delta i_d-(px_q(p)+r)\,\Delta i_q+\\&(\psi_{d0}p+e_{d0})\,\Delta\delta=+\cos\delta_0\,\Delta e-\omega_0G(p)\,\Delta E\\&-(\psi_{q0}+i_{q0}x_d(p))\,\Delta i_d+(\psi_{d0}+i_{d0}x_q(p))\times\\&\qquad\Delta i_q+Mp^2\Delta\delta=\Delta T-i_{q0}G(p)\,\Delta E\end{aligned}\right\}\quad(5)$$

Hollow Pipes of Relatively Small Dimensions

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Summary

SEVERAL cross sectional shapes for hollow-pipe transmission lines are described that provide lower operating frequencies for given outside dimensions than do the simple shapes heretofore proposed. The theory for one such line, the "septate coaxial cable" is derived, and experiments are reported. Cavity resonator embodying these principles are also described.

Introduction

The hollow-pipe type of conductor[1,2] for ultrahigh-frequency electromagnetic energy, although possessing several desirable features, has the disadvantage that its transverse dimensions are relatively large; namely, of magnitude comparable to the wave length. The object of this paper is to lessen this encumbrance by describing pipes that have transverse dimensions several times smaller than those of the simple forms previously proposed.*

The principle underlying the improved conductors derives from the properties of the $H_{0,1}$-waves[3] in a pipe of flat rectangular cross section, figure 1*A*. In this case, the critical wave length λ_0, i.e. the wave length above which no transmission takes place, is independent of d and depends on l only ($\lambda_0 = 2l$). By bending or folding the pipe transversely, keeping the separation between the top and bottom sides unchanged, a hollow conductor of smaller over-all dimensions may be obtained that has the same general internal configuration as the rectangular pipe. The deformation of the cross section may take place in a number of ways, several of which are shown in figure 1*B* to *D*. In the illustrations, the corresponding dimension l is indicated by a dotted line. In each of the deformed conductors there is a type of wave with a critical frequency approximately equal to $2l$, but the over-all dimensions of the deformed pipe are considerably smaller than those of 1*A* or of a circular pipe of the same critical value.

The conductor 1*B* may be thought of as a concentric line in which the center conductor is connected to and supported from the outer conductor along its entire length by a conducting radial rib or strip. Dielectric supports and spacers are unnecessary and the system is a uniconductor. Transmission in this particular example of the deformed pipes, which is here termed the *septate coaxial cable*, has been analyzed theoretically. Experiments have been made on it and on the partitioned rectangular type of 1*D*. The remainder of the paper presents the more important results of this research.

Theory of the Septate Coaxial Cable

The cylindrical co-ordinate system θ, r, x, in which x is the longitudinal co-ordinate, is indicated in figure 1*C*. A variation of all field components with the time t and with x of the form $e^{-hx+i\omega t}$ will be assumed, where h is the propagation constant, $\omega = 2\pi$ times frequency and $i = \sqrt{-1}$. The propagation constant for a pipe with a perfectly conducting wall is $i\beta$, where β is the phase constant. The attenuation constant α will not be given in this paper; although laborious, it may be calculated by known methods. The interior of the pipe has the dielectric constant ϵ, which is $10^{-11}/36\pi$ farads per centimeter for vacuum, air, and other gases that are primarily of interest for practical applications, and the permeability μ which is $4\pi \times 10^{-9}$ henries per centimeter for vacuum or gas.

The analysis begins with the wave equation in cylindrical co-ordinates, which is used to obtain solutions for the longitudinal field components E_x or H_x:

$$\left.\begin{matrix} E_x \\ H_x \end{matrix}\right\} = \sin(k\theta + C_k)\left\{C_1 J_k\left(r\sqrt{h^2+\left(\frac{\omega}{c}\right)^2}\right) + C_2 Y_k\left(r\sqrt{h^2+\left(\frac{\omega}{c}\right)^2}\right)\right\} e^{-hx+i\omega t} \quad (1)$$

J_k and Y_k are Bessel functions of first and second kind, respectively, and of order k; the constant $C_1, \ldots C_3$ and the quantities k and h are determined from

Paper 41-8, recommended by the AIEE committee on communication and presented at the AIEE winter convention, New York, N. Y., January 27-31, 1941. Manuscript submitted November 5, 1938; made available for preprinting November 4, 1940.

Much of the analytical and the experimental work of this paper was carried out in the Master's Thesis "Electromagnetic Waves in Longitudinally Partitioned Hollow Pipes," by H. Schaevitz, M.I.T., 1938.

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1. For all numbered references, see list at end of paper.

* It is known that the dimensions of an ordinary hollow-pipe conductor may be reduced by filling its interior with a substance of dielectric constant substantially greater than unity. This method, however, introduces large losses because of the imperfectness of available dielectrics. The type of cables described herein accomplish the same result without incurring such dielectric losses. They will also effect a further reduction of dimensions in the dielectric filled pipes.

and equation 3 reduces to

$$D = M\beta^2[(p\pi_d(p)+r)(p\pi_q(p)+r) + \omega_0{}^2\pi_d(p)\pi_q(p)] + (\psi_{d0}+i_{d0}\pi_d(p))\times[(p\pi_d(p)+r)(\psi_{q0}p+e_{q0}) + \omega_0{}^2\pi_q(p)(\psi_{q0}p+e_{q0})] + (\psi_{q0}+i_{q0}\pi_q(p))\times[-\omega_0{}^2\pi_d(p)(\psi_{d0}p+e_{d0}) + (p\pi_q(p)+r)(\psi_{q0}p+e_{q0})] \quad (6)$$

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boundary conditions. The other components of field are obtained from (1) by means of Maxwell's equations. Two different kinds of solutions exist: one, in which $H_z=0$, corresponding to hollow-pipe waves of the E type; and the other, in which $E_z=0$, corresponding to hollow-pipe waves of the H type. In each instance, the boundary conditions for a perfectly conducting wall, i.e., the vanishing of the tangential component of electric field on all surfaces of the conductor, are next imposed on the solutions. A transcendental equation for the propagation constant h results, the solution for which allows the critical frequency, wave length and the other transmission properties to be calculated.

$E_{n,m}$-Waves

We place $H_z=0$ and derive the other field components from E_z in (1). The boundary condition requires $E_z=0$ for $\theta=0$, θ_0 and $r=a$, b. We find that $C_3=0$ and $k=n\pi/\theta_0$, where $n=1, 2\ldots$ and that the field is given by:

$$\left.\begin{aligned}
E_z &= \sin k\theta\cdot G\cdot e^{-hz+i\omega t}\\
E_\theta &= \frac{-hk}{r\left[h^2+\left(\frac{\omega}{c}\right)^2\right]}\cos k\theta\cdot G\cdot e^{-hz+i\omega t}\\
E_r &= \frac{-h}{h^2+\left(\frac{\omega}{c}\right)^2}\sin k\theta\cdot\frac{dG}{dr}\cdot e^{-hz+i\omega t}\\
H_\theta &= \frac{i\omega\epsilon}{h^2+\left(\frac{\omega}{c}\right)^2}\sin k\theta\cdot\frac{dG}{dr}\cdot e^{-hz+i\omega t}\\
H_r &= \frac{i\omega k}{r\left[h^2+\left(\frac{\omega}{c}\right)^2\right]}\cos k\theta\cdot G\cdot e^{-hz+i\omega t}\\
H_z &= 0
\end{aligned}\right\} \quad (2)$$

where

$$G=C_1J_k\left(r\sqrt{h^2+\left(\frac{\omega}{c}\right)^2}\right)+C_2Y_k\left(r\sqrt{h^2+\left(\frac{\omega}{c}\right)^2}\right)$$

The transcendental equation for h is:

$$\frac{J_k\left(a\sqrt{h^2+\left(\frac{\omega}{c}\right)^2}\right)}{Y_k\left(a\sqrt{h^2+\left(\frac{\omega}{c}\right)^2}\right)}=\frac{J_k\left(b\sqrt{h^2+\left(\frac{\omega}{c}\right)^2}\right)}{Y_k\left(b\sqrt{h^2+\left(\frac{\omega}{c}\right)^2}\right)} \quad (3)$$

This equation may be solved approximately by means of McMahon's series[4] to get β, where $h=i\beta$:

$$\beta=\sqrt{\left(\frac{\omega}{c}\right)^2-\left[\frac{m\pi}{b-a}+\frac{(4\pi^2n^2-\theta_0^2)(b-a)}{8abm\pi\theta_0^2}+\ldots\right]^2} \quad (4)$$

where $m=1, 2, 3\ldots$.

The critical frequency is the root of the equation $\beta=0$:

$$f_0=\frac{c}{2\pi}\left[\frac{m\pi}{b-a}+\frac{(4\pi^2n^2-\theta_0^2)(b-a)}{8abm\pi\theta_0^2}+\ldots\right] \quad (5)$$

The transmission characteristics may be found in the usual way: Wave length in pipe $=\lambda_p=\frac{2\pi}{\beta}$; phase velocity $=v_p=\frac{\omega}{\beta}$; group velocity $=v_g=\frac{d\omega}{d\beta}$.

In the septate coaxial cable, $\theta_0=2\pi$. For the special case of $n=1$, k becomes $1/2$ and J_k and Y_k reduce to the following form:

$$\left.\begin{aligned}
J_{1/2}(x) &= \sqrt{\frac{2}{\pi x}}\sin x\\
Y_{1/2}(x) &= \sqrt{\frac{2}{\pi x}}\cos x
\end{aligned}\right\} \quad (6)$$

where

$$x=r\sqrt{h^2+\left(\frac{\omega}{c}\right)^2}$$

Consequently, the phase constant becomes

$$\left.\begin{aligned}
\beta &= \sqrt{\left(\frac{\omega}{c}\right)^2-\left(\frac{m\pi}{b-a}\right)^2}\\
\text{and}\quad \lambda_g &= \frac{2(b-a)}{m}
\end{aligned}\right\} \quad (7)$$

For $m=1$, the critical wave length is equal to twice the radial distance between the outer and inner circular walls; this result bears a striking similarity to the $H_{1,0}$-wave in a rectangular pipe.

The electric intensity in the transverse cross section is given by:

$E_{1,m}$-Wave

$$\left.\begin{aligned}
E_r &= \frac{C_4}{\sqrt{r}}\sin\frac{\theta}{2}\left[\frac{m\pi}{b-a}\cos\left(\frac{m\pi}{b-a}r-C_5\right)-\frac{1}{2r}\sin\left(\frac{m}{b-a}r-C_5\right)\right]e^{-hz+i\omega t}\\
E_\theta &= \frac{C_4}{2r\sqrt{r}}\times\cos\frac{\theta}{2}\sin\left(\frac{m\pi}{b-a}r+C_5\right)e^{-hz+i\omega t}
\end{aligned}\right\} \quad (8)$$

where C_4 and C_5 are new constants.

Sketches of the field configurations of the $E_{1,1}$-wave and the $E_{2,1}$-wave in the transverse section are shown in figure 2. It is apparent that higher order E-waves may be considered as built up from $E_{1,1}$-waves. We observe that in the $E_{2,1}$-wave a second septum may be placed within the pipe at $\theta=\pi$, providing two independent and separate hollow-pipe channels having the same critical frequency as that of the $E_{2,1}$-wave in the septate coaxial line. This idea has been suggested by Schelkunoff.[5] Figure 3 illustrates the relations between the ratio of the critical wave length to the radius of the outer tube, λ_0/b, and the angular dimension θ_0; evidently the longest critical wave length is afforded by $\theta_0=2\pi$, that is, by the septate coaxial line. The critical wave length increases with increasing b/a, as is also illustrated in figure 3.

$H_{n,m}$-Waves

We place $E_z=0$ and derive the remaining field components from H_z in (1), obtaining:

$$\left.\begin{aligned}
H_z &= \cos\left(\frac{n\pi}{\theta_0}\theta\right)\cdot G\cdot e^{-hz+i\omega t}\\
H_\theta &= \frac{h\frac{n\pi}{\theta_0}}{r\left[h^2+\left(\frac{\omega}{c}\right)^2\right]}\sin\left(\frac{n\pi}{\theta_0}\theta\right)\cdot G\cdot e^{-hz+i\omega t}\\
H_r &= \frac{-h}{h^2+\left(\frac{\omega}{c}\right)^2}\cos\left(\frac{n\pi}{\theta_0}\theta\right)\frac{dG}{dr}\cdot e^{-hz+i\omega t}\\
E_\theta &= \frac{i\omega\mu}{h^2+\left(\frac{\omega}{c}\right)^2}\cos\left(\frac{n\pi}{\theta_0}\theta\right)\cdot\frac{dG}{dr}\cdot e^{-hz+i\omega t}\\
E_r &= \frac{i\omega\mu\frac{n\pi}{\theta_0}}{r\left[h^2+\left(\frac{\omega}{c}\right)^2\right]}\sin\left(\frac{n\pi}{\theta_0}\theta\right)\cdot G\cdot e^{-hz+i\omega t}
\end{aligned}\right\} \quad (9)$$

where k and G have the same meaning as before. The transcendental equation for h is now

$$\frac{J_k'\left(a\sqrt{h^2+\left(\frac{\omega}{c}\right)^2}\right)}{Y_k'\left(a\sqrt{h^2+\left(\frac{\omega}{c}\right)^2}\right)}=\frac{J_k'\left(b\sqrt{h^2+\left(\frac{\omega}{c}\right)^2}\right)}{Y_k'\left(b\sqrt{h^2+\left(\frac{\omega}{c}\right)^2}\right)} \quad (10)$$

The approximate solution of (10) provides the values:

$$\left.\begin{aligned}
\beta &= \sqrt{\left(\frac{\omega}{c}\right)^2-\left[\frac{m}{b-a}+\frac{(4\pi^2n^2+3\theta_0^2)(b-a)}{8abm\pi\theta_0^2}+\ldots\ldots\right]^2}\\
f_0 &= \frac{c}{2\pi}\left[\frac{m\pi}{b-a}+\frac{(4\pi^2n^2+3\theta_0^2)(b-a)}{8abm\pi\theta_0^2}+\ldots\ldots\right]
\end{aligned}\right\} \quad (11)$$

A sketch of the field configuration of the $H_{2,1}$-wave is reproduced in figure 2. In this wave, there is only one component of electric intensity, namely in the angular direction, and this component varies

approximately as a half-sinusoid radially. A comparison of (11) with (4) and (5) shows that the critical frequency has the same functional form as that for the E-wave.

$H_{1,0}$-Waves

If we let $\theta_0 \to 0$ as $a \to b \to \infty$, the cross section of the pipe approaches a rectangle, and consequently there must be a wave in the septate coaxial cable which will degenerate into the $H_{n,0}$-wave in the rectangular pipe. Thus there is reason to believe that an approximate solution may be obtained for $m=0$ even though (1) is not strictly valid for this value of m. Calculations are possible by graphical methods for the special case $n=1$ and $\theta_0=2\pi$. For this case $k=1/2$, and

$$G=\sqrt{\frac{2}{\pi r\sqrt{h^2+\left(\frac{\omega}{c}\right)^2}}}\left[C_1\sin\left(r\sqrt{h^2+\left(\frac{\omega}{c}\right)^2}\right)-C_2\cos\left(r\sqrt{h^2+\left(\frac{\omega}{c}\right)^2}\right)\right] \quad (12)$$

After applying the boundary condition $\frac{dG}{dr}=0$ for $r=a$, b and simplifying we obtain the following transcendental equation for h:

$$\tan\left[(b-a)\sqrt{h^2+\left(\frac{\omega}{c}\right)^2}\right]=\frac{2(b-a)\sqrt{h^2+\left(\frac{\omega}{c}\right)^2}}{1+4ab\left[h^2+\left(\frac{\omega}{c}\right)^2\right]} \quad (13)$$

This equation has been solved by graphical means for specific ratios of a and b. The constant β and λ_0 can be found in the usual way.

The importance of this wave is that it has the lowest critical frequency of any wave in a septate coaxial line. To illustrate this point, let us consider the case in which $a \to b$. Equation 13 then becomes simply

$$\sqrt{h^2+\left(\frac{\omega}{c}\right)^2}=\frac{1}{2b}$$

i.e.

$$\beta=\sqrt{\left(\frac{\omega}{c}\right)^2-\left(\frac{1}{2b}\right)^2} \quad (14)$$

and the corresponding critical wave length is:

$$\lambda_0=2\cdot 2\pi b \quad (15)$$

that is, the critical wave length is twice the circumference of the pipe. The longest critical wave length in a rectangular pipe is twice the width of the pipe, and the longest critical wave length in a circular pipe is 3.41 times the radius. Thus, *the limiting critical wave length of the septate line is greater than that of a circular hollow*

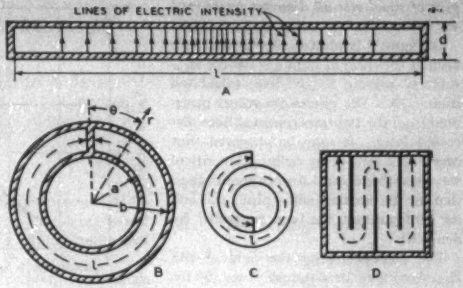


Figure 1. Transverse cross sections of several shapes of hollow pipes; (A) flat rectangular, (B) septate coaxial, (C) spiral, (D) folded. The critical frequencies are approximately the same for each pipe

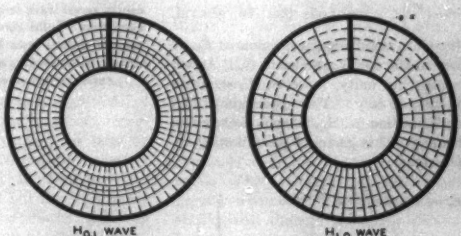


Figure 2. Configuration of the electric field intensity for four types of waves in a septate coaxial cable

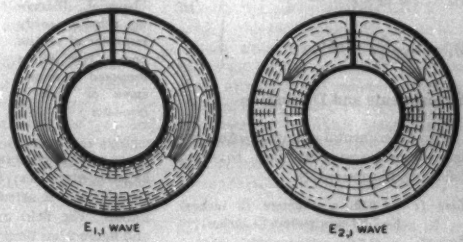
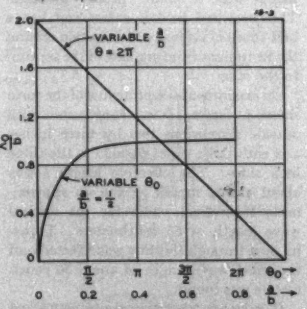


Figure 3 (below). $E_{1,1}$ wave. Relative critical wave length λ_0/b versus a/b in a septate coaxial cable ($\theta_0=2\pi$), and λ_0/b versus θ_0 for $a/b=1/2$



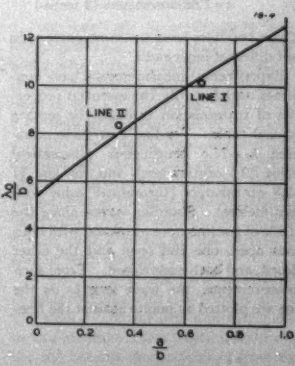


Figure 4. $H_{1,0}$ wave in septate coaxial cable. Relative critical wave length λ_0/b versus a/b. The small circles indicate measured values from two experimental cables

pipe of equal over-all diameter by the ratio $4\pi/3.41=3.68$.

In figure 4 is plotted the ratio of λ_0/b against the ratio of radii a/b for the $H_{1,s}$-wave in septate coaxial line, calculated from (13). The circles are values measured from the two experimental lines discussed later. It may be observed that even for a zero inner radius, the critical wave length is about 1.5 times greater than that for the circular hollow pipe; this latter configuration has been suggested by Sonoda.[6]

The expressions for the field of the $H_{1,s}$-wave may be obtained from (9) by substituting the appropriate values for $h^2+\left(\frac{\omega}{c}\right)^2$. One finds that, in general, there is a small angular component E_ϕ, as well as the radial component E_r. As b/a approaches unity, however, E_ϕ vanishes leaving E_r only. This approximate field configuration for $H_{1,s}$-wave is sketched in figure 2 and is given by the following expressions:

$$\left.\begin{aligned} E_r &= C2i\omega\mu b \sin\frac{\theta}{2}\, e^{-hz+kct} \\ H_\theta &= C2hb \sin\frac{\theta}{2}\, e^{-hz+kct} \\ H_z &= C \cos\frac{\theta}{2}\, e^{-hz+kct} \end{aligned}\right\} \quad (16)$$

Experiments and Discussion

Two experimental septate coaxial lines have been investigated that have the following dimensions:

Line I: $a=5.08$ centimeters (2 inches), $b=7.62$ centimeters (3 inches)

Line II: $a=2.54$ centimeters (1 inch), $b=7.62$ centimeters (3 inches)

These two lines have the same outer radii but different inner radii.

Experimental measurements have confirmed satisfactorily the essential properties of transmission through the septate coaxial cable. For line I we have measured $\lambda_0=77.5$ centimeters (theoretical value 79.5 centimeters), and for line II 63.5 centimeters (theoretical value 61.3 centimeters). Standing waves along the inside of the line were measured with both ends open, one end open and the other closed, and both ends closed. From such measurements, the wave lengths on the line are plotted as points against the free-space wave lengths in figure 5 for the two experimental lines; the solid curves are theoretical. A satisfactory agreement is found. The field configuration of (16) and figure 2 has been verified by measurements with a small "probe" antenna. The measured field is radial and has a half-sinusoid intensity distribution around the 2π radians from one side of the septum to the other.

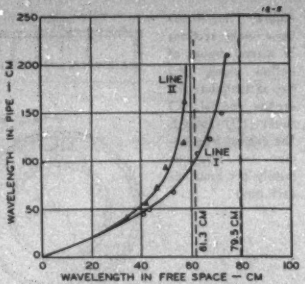
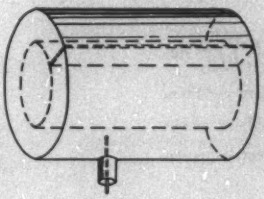


Figure 5. Wave length in two septate coaxial cables versus wave length in free space of the excitation. Solid curves give the theoretical values; dotted lines indicate the theoretical critical wave length, and the circles and triangles represent experimental values



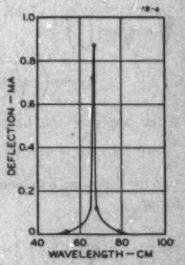


Figure 6. Illustrating a hollow cavity resonator of septate coaxial type and a measured response curve of such a resonator

An experimental septate line of the form shown in figure 1*D* was constructed with outside dimensions two by three inches and with three vanes parallel to the three inch sides. The effective length l was about eleven inches, giving an approximate theoretical value for the critical wave length of 55 centimeters. Transmission through this line was effected and a critical wave length of about 50 centimeters was found.

It is known that the cavity contained within a section of hollow pipe closed at both ends manifests pronounced resonance characteristics.[1,3] A highly effective or "high Q" resonator for use in conventional circuits is provided by such a cavity when a connection to the cavity is made by inserting a short length of wire into the cavity through a small hole. Septate lines are readily adapted to this use and offer the advantage of a relatively low resonant frequency for given over-all dimensions. Figure 6 shows a resonator of this kind and a measured response curve obtained in a cavity established in the experimental line II between transverse sheet-metal annuli. Improved construction would improve markedly the sharpness of resonance. The sketch of figure 6 will also serve to show one method of connecting a septate-line terminal to conventional sending or receiving apparatus. Another cavity resonator based on the same principles and providing, too, a relatively long resonant wave length comprises two concentric metal spheroids connected together by a single radial metal rod, which may also serve as a supporting member for the inner spheroid.

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Impulse and 60-Cycle Characteristics of Driven Grounds

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FELLOW AIEE

I. Introduction

DRIVEN grounds are important in electric power transmission and distribution. In fact, they comprise one of the essential elements in the art of lightning protection. Yet, to this day, the value of protection derived from grounds under actual operating conditions of lightning discharge is difficult to state in full quantitative measure. And the reason for this situation lies partly in the lack of fundamental knowledge of the impulse characteristics of driven grounds. In part, the difficulty also is due to the complex factors that inherently make up driven grounds and ground systems.

A comprehensive survey of principles and methods on driven grounds was issued in 1918 by the Bureau of Standards.[1] Further contributions have appeared since, some presenting new developments and findings,[2] others dealing on theoretical aspects of the problem,[3] and a third group bearing on related questions.[4] In recent years, progress has been centered on the immediate field of application. Here the emphasis has been to obtain effective service with such methods of grounding as lend themselves particularly to economical installation. For instance, a common practice with some utilities nowadays is to drive rods to considerable depths, even down to bedrock, so as to attain the lowest measurable resistance. A recognized practice for securing low-resistance grounds is also to place a sufficient number of electrodes in parallel (multiple grounds). Still another expedient is that of reducing the resistivity of the soil immediately surrounding the electrode by suitable treatment with common salt (NaCl) or other conducting solution. All these developments have been based largely either on 60-cycle values or on closely similar methods of testing. And from the measured 60-cycle values plus what experience would ensue there have been established present practices.

It is a fact that the 60-cycle methods of measurement have the great merit of simplicity[5,6] and it is conceded that experience can often rationalize methods of evaluating performance that are not altogether fundamental. Yet the need of establishing the performance of grounds under the actual service conditions of lightning discharge has long been recognized. In this connection, the tests by H. W. Towne[7] in 1928 and more recently an investigation by H. Norinder[8] has contributed to point out the significance of the impulse characteristics of driven grounds—even though both investigations are somewhat limited in scope considering the extent and practical importance of the subject.

Those versed in the art know that the impulse resistance of a driven ground is below the corresponding megger or 60-cycle measured values. The practice usually followed, to consider the megger values as a basis for design, is also a recognition of this fact. There are other factors which affect design and economy of installation, but these need not be gone into at this time. An immediate fundamental need is for impulse data on actual driven grounds, under impulse currents well approaching lightning conditions. The results of the investigation presented in this paper should therefore be timely and helpful to the art of lightning protection.

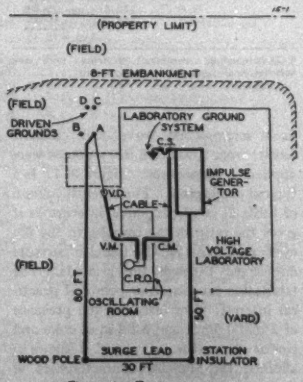

Figure 1. Test arrangement

CRO—Cathode-ray oscillograph
VM—Voltage measurement
VD—Voltage divider
CM—Current measurement
CS—Current shunt

II. Test Arrangement

The Sharon High-Voltage Laboratory is located in the open. This is a favorable circumstance that has facilitated the investigation, for the grounds can be driven in the natural soil within easy reach of a well-equipped impulse laboratory. The arrangement that was used is shown in figure 1.

The impulse generator and the instruments are grounded to the common, low-resistance grid of the laboratory, which measured with the megger 0.9 ohm to earth. The voltages of the driven grounds were recorded at the cathode-ray oscillograph through a voltage divider. Likewise the impulse currents discharged through the driven grounds were measured at the oscillograph, by means of a suitable shunt inserted in the grounded end of the impulse generator. The technique of testing and measurement complies essentially with the recognized methods described in AIEE Standards No. 4 (1940) and in the literature. Other details on the test arrangement will be apparent from figure 1 and the following.

III. Physical Characteristics of Driven Grounds

Four one-inch diameter steel rods, designated as *A*, *B*, *C*, and *D* in figures 1 and 2, were driven in the natural soil outside the laboratory in 1933. They have been in the soil ever since. Two of the rods were driven nine feet in the earth, the other two struck rocks at seven and one-half feet and could not be driven deeper. Early in 1940, after this investigation, two of the rods were removed for inspection. There was no evidence of rusting of the metal at the surface in contact with the soil.

The soil of the grounds is a combination of shale and clay with a mixture of gravel and sand. The earth is normally moist in this location. The physical nature of the soil became more apparent from the examination of a six-foot diameter ten-foot deep hole that was dug in May 1940 near the laboratory at about 25 feet from the location of the grounds. First, sev-

Paper 41-5, recommended by the AIEE committee on power transmission and distribution and presented at the AIEE winter convention, Philadelphia, Pa., January 27-31, 1941. Manuscript submitted September 9, 1940; made available for preprinting October 25, 1940.

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1. For all numbered references, see list at end of paper.

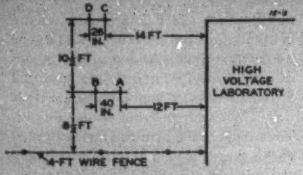

Figure 2. Physical characteristics of driven grounds: A, B, C, and D

Length of rods—ten feet
Diameter of rods—one inch
Taper of end in ground—four inches
Metal (rods)—steel
Depth in ground, *A* and *B*—108 inches
Depth in ground, *C* and *D**—90 inches
Rods driven in 1933

Class of soil—shale and clay with mixture of gravel and sand. Earth naturally moist. Rods in natural soil. Coke cinder on ground surface along fence, extending to rod *A*. Natural surface of soil elsewhere

**C* and *D* struck rocks

eral inches of vegetation soil was removed. Then a combination of clay, sand, and gravel followed to a depth of five feet. In fact a strata of about a foot consisted of a compact layer of gravel and rocks. From five feet down to ten feet, the bottom of the hole, the soil consisted of a thick blue clay. In digging the hole, water started seeping in at a depth of three feet. A rod consisting of multiple sections was driven straight down in the field nearby. It struck solid bedrock at 30 feet. Still other details of the terrain and adjacent objects will be apparent from figures 1 and 2. In short, the class and the nature of the soil are quite typical of conditions that are encountered in Western Pennsylvania and also in other sections of the country.

IV. Tests

(*A*). First series. These tests were completed in November 1939 before the ground had frozen at all. The winter in 1939–1940 got under way late in Western Pennsylvania. Sixty-cycle values for the four driven grounds and for combinations of them are summed up in table I. The voltmeter-ammeter method with sinusoidal waves was applied in these and later tests. Currents ranged from one to five amperes and in one case up to ten amperes. Within these limits the resistance is found to decrease two to three per cent with increase in the current.

The results of the impulse tests which were made at this same time are summarized in table II. The footnote describes the arrangement of the generator. A

Table I. Sixty-Cycle Measurements of Grounds

(Data of Tests 11/27/39)

Driven Grounds	Ammeter (Amps)	Voltmeter* (Volts)	Resistance (Ohms)
A alone	1.01	43.4	43.0
	2.00	86.0	43.0
	2.98	127.2	42.7
	4.00	170.0	42.5
	4.50	193.0	42.1
		Avg. =	42.66
B alone	4.75	189.5	39.9
	4.00	160.5	40.1
	3.01	120.5	40.0
	2.03	81.2	40.0
	1.02	41.5	40.7
		Avg. =	40.1
C alone	4.98	178.5	35.8
	4.30	190.5	35.9
	4.00	142.2	35.5
	3.01	107.0	35.6
	2.13	76.7	36.0
	1.03	37.6	36.4
		Avg. =	35.87
D alone	1.01	37.5	37.2
	2.12	77.3	36.5
	3.01	107.8	35.8
	4.02	143.3	35.7
	5.0	178.0	35.6
	5.35	190.2	35.9
		Avg. =	36.12
A and B in parallel	2.54	66.6	25.9
	3.04	77.1	25.4
	3.98	102.3	25.7
	5.00	129.2	25.9
	6.00	154.0	25.6
	7.00	178.5	25.5
		Avg. =	25.66
C and D in parallel	5.32	190.2	36.1
	4.96	176.0	35.4
	4.03	142.5	35.4
	3.04	107.3	35.3
	2.14	76.7	35.8
	1.03	37.0	35.9
		Avg. =	35.65
A, B, C, and D in parallel	1.28	21.7	16.95
	2.01	33.0	16.45
	2.99	49.5	16.53
	3.97	65.0	16.40
	5.0	82.0	16.40
	6.1	100.0	16.40
	7.1	115.8	16.30
	8.6	139.8	16.30
	10.0	163.5	16.35
		Avg. =	16.45

* Corresponding readings of rms and avg voltmeters all agree within 1.5 per cent.

6x13 microsecond wave and currents (crest) from 2,000 to 8,000 amperes were applied in these tests. Figure 3-*AF* is a typical oscillogram. The seventh column of table II is of particular interest as it gives the ratio of the impulse to the 60-cycle resistance for the impulse currents discharged through the grounds. The tabulation reveals other points of practical interest. For instance, the presence of a metal fence and a fill-in of coke and cinder adjacent to rods *A* and *B* (figure 2) affected the impulse characteristics of these grounds, particularly at the higher currents. This illustrates the various considerations that require attention when establishing grounds.

(*B*). Second series. The second series of tests was made in January 1940. By this time the ground had frozen at the surface six or eight inches and the temperature had dropped. The resistance had accordingly increased about ten per cent. Through the assistance of the local utility (Pennsylvania Power Company), megger readings of the grounds were taken. These with the 60-cycle values are reported in table III.

The impulse data are summarized in table IV. In these tests, the generator was set for a 12x50 microsecond wave and currents (crest) from 700 to 6,500 amperes were available. Typical oscillograms of the current and the voltage are shown in *AX* and *BJ* of figure 3. In the next to the last column of table IV is reported the ratio of the impulse to the 60-cycle resistance for these tests. Again when the two grounds adjacent to the fence, particularly rod *A*, were tested at the higher currents, surface flashover and apparent breakdown in the earth took place. The oscillograms of *BT* (figure 3) illustrate this effect.

(*C*). Other tests. Sixty-cycle check tests on the grounds were made in the summer (1940). They are reported in table III. The data in this table thus show the seasonal variation of the ground resistances.

V. Impulse and 60-Cycle Characteristics

As shown in figure 4, a definite relation holds between the ratio of the impulse to the 60-cycle resistance and the impulse current. The values plotted are for the tests on grounds *C*, *D*, *B*, and the combination *C* and *D* (tables II and IV). The test data are for 6x13 microsecond and 12x50 microsecond waves, but it appears reasonable that the curve applies for impulses over a wider range of waves as encountered in the field. It should be noted that successive applications or tests repeated at different times did not affect the ratio, other than an amount due to inherent variations.

In rounded figures the ratio for these grounds at 1,000, 2,500, 5,000 and 10,000 amperes decreases respectively to the values 0.85, 0.75, 0.65, and 0.55. At higher currents, as 20,000 amperes—provided the potentials developed can be sustained by the grounds, from extrapolation of the curve the ratio does not seem to come materially below 0.50. A lightning stroke to a distribution or a transmission circuit or to a lightning-rod system in general is likely to discharge to earth through more than one path to ground. Therefore the range of currents in figure 4 covers field conditions from a

traveling surge to a direct stroke of lightning.

Two factors in particular governed the low impulse breakdown from rod *A* to the adjacent wire fence. Rod *A* was driven eight and one-half feet from the fence, but what seems to have been even a greater influencing factor was the presence of a fill-in of coke and cinders on the ground layer from the fence to the rod. The relative proximity to rod *A* affected rod *B* somewhat, but only at the higher currents. Rods *C* and *D* on the other hand were amply removed from adjacent bodies and were well surrounded by homogeneous and natural soil, with the result that they sustained the impulse voltages up to the top limit of the test. The performance of rod *A* illustrates emphatically that other considerations govern the installation of grounds besides those dictated by 60-cycle measurements alone.

The 60-cycle resistance for the various parallel combinations of the four rods (table III) is approximately the amount expected from calculation[2] or from previous studies.[1] For example, *A* and *B* in parallel calculates 29 ohms, *B* and *D* 24.5 ohms and *A*, *B*, *C*, and *D* 18.5 ohms. Rods *C* and *D* in parallel show no reduction due in part to the close proximity of the electrodes and possibly to other factors residing in the earth. However, grounds *C* and *D* were good grounds to test with as these were in natural and homogeneous earth, uninfluenced by extraneous bodies and least affected by seasonal variations such as result from changes of the temperature and moisture content in the earth (table III).

For parallel grounds liberally spaced and of normal characteristics, the ratio of impulse to 60-cycle resistance for the individual grounds should hold adequately close for the parallel combination when applied on the basis of the current per rod. The only data available to corroborate this point are the impulse tests on *B* and *D* in parallel (table IV).

A characteristic fundamentally significant is the variation of the resistance of grounds during the impulse discharge. For instance, from the voltage and current oscillograms of *BJ* in figure 3, the resistance from ten to fifty microseconds is found to average 31.5 ohms within about one per cent. Other typical oscillograms are analyzed in table V. The grounds of this investigation exhibited markedly constant resistance, usually within a ten per cent variation, over the part of the discharge that can be considered of more practical significance, i.e., for currents above 50 per cent crest. The relatively constant value of the impulse resistance is apparent also from figure 4 which shows that for a given

Figure 3. Typical oscillograms of impulse voltages (E) and currents (I)

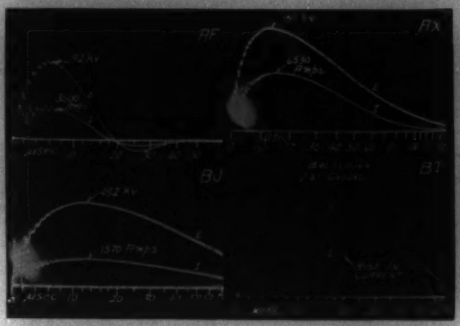

Table II. Impulse Measurements of Grounds*

(Date of Tests 11/28/39)

Driven Grounds	Cathode Ray Oscillogram	Wave Form**	Impulse Values: Measured Ground Crest Values Kv	Amps	Impulse Resistance (Ohms)	Ratio of Impulse to 60-Cycle Resistance	Comments
C alone	AD	Current wave	166..	7,680	21.6	0.60	Refer table I for avg. 60-cycle resistance values. For typical oscillogram, see AF in figure 3
	AE	6x13 MS	131..	5,500	23.9	0.66	
	AF	Voltage wave	92..	3,500	26.0	0.73	
	AG	6x13 MS	56..	2,050	27.5	0.77	
D alone	W-X	Ditto	59..	2,240	26.5	0.73	Ditto
	Y		93..	3,330	27.9	0.78	
	Z-AA		95..	3,330	28.5	0.79	
	AB		132..	6,020	21.9	0.61	
	AC		166..	7,680	21.6	0.60	
C and D in parallel	AH	Ditto	58..	2,100	27.6	0.77	Ditto
	AI		92..	3,520	26.2	0.73	
	AJ-AK		133..	4,800	27.6	0.77	
	AL		166..	7,050	23.8	0.67	
B alone	AM	Ditto	159..	7,050	22.6	0.56	Collapse of voltage near crest on oscillograms AM and AN due to breakdown in the ground. Current in AM built up to 8,070 amps
	AN		119..	4,870	24.4	0.61	
	AO		100..	3,200	31.3	0.78	
	AP		61..	2,100	29.2	0.73	
A alone	F-G	Oscillatory wave, 35 MS period	52..	11,400	....	....	Low impulse resistance caused by breakdown in ground to wire fence. Adjacent ground and wire fence a factor
	M-N		51..	8,060	....	....	
	K-L		43..	4,670	....	....	
	I-J		33..	2,750	....	....	
A, B, C, and D in parallel	B-C	Oscillatory wave, 35 MS period	53..	11,300	....	....	Impulse resistance much similar to values of A alone. Adjacent ground and wire fence a factor
	Q-R		46..	8,330	....	....	
	S-T		39..	4,920	....	....	
	U-V		31..	3,070	....	....	

* Impulse-generator arrangement consisted of ten, 100 kv, 1.5, microfarad capacitor banks in series. Effective series capacitance and inductance of test circuit were respectively 0.15, microfarad and 210, microhenrys. No series resistance inserted in generator (figure 1).

** Positive polarity.

Table III. Sixty-Cycle and Megger Measurements of Grounds

Driven Grounds	Average 60-Cycle Resistance* (Ohms)	Average Megger Resistance** (Ohms)	Average 60-Cycle Resistance*** (Ohms)
A(alone)	46.8	49	33.2
B(alone)	44.1	45	31.3
C(alone)	39.1	39.5	35.7
D(alone)	38.8	38.5	32.0
A and B (in parallel)	28.0	28	
C and D (in parallel)	39.0	39	
B and D (in parallel)	22.4		
A, B, C, and D (in parallel)	17.8	18	

* Measurements by voltmeter-ammeter method, as in table I. Date of tests 1/15/40.

** Measurements recorded with G. J. Biddle Megger. Date of tests 1/31/40.

*** Measurements by voltmeter-ammeter method as in table I. Date of tests 7/22/40.

Table IV. Impulse Measurements of Grounds*

(Date of Tests 1/2/40)

Driven Grounds	Cathode Ray Oscillogram	Wave Form***	Impulse Values: Measured Ground Crest Values Kv	Amps	Impulse Resistance (Ohms)	Ratio of Impulse to 60-Cycle Resistance	Comments
D alone	AQ	Current wave 13x48 MS Voltage wave 12x50 MS	24.0	735	32.6	0.85	Refer table II for avg. 60-cycle and Megger resistance values.** For typical oscillogram, see AX in figure 3
	AR		47.7	1,505	31.7	0.82	
	AS		70	2,300	30.4	0.79	
	AT		91	3,140	29.0	0.75	
	AU		110	4,160	26.4	0.69	
	AV		132	5,310	24.9	0.65	
	AW		153	6,340	24.2	0.63	
	AX		151	6,530	23.1	0.60	
	AY		24.4	672	36.3	0.94	
	BE		23.7	672	35.2	0.91	
	BF		89.6	3,390	26.4	0.69	
	BG		129	5,560	23.2	0.60	
	BK		47.6	1,600	29.9	0.78	
C alone	BB	Ditto	109	4,420	24.7	0.63	For typical oscillogram see BJ in figure 3
	BC		69.8	2,340	29.8	0.76	
	BD		24.4	640	38.2	0.97	
	BH		125.5	5,250	23.9	0.61	
	BI		89.3	3,240	27.5	0.70	
	BJ		49.2	1,570	31.4	0.80	
C and D in parallel	BL	Ditto	23.7	737	32.1	0.82	Ditto
	BM		47.4	1,600	29.6	0.76	
	BN		68.5	2,240	30.6	0.79	
	BO		89.2	3,330	26.8	0.69	
	BP		112	4,160	26.9	0.69	
	BQ		131	5,500	23.8	0.61	
	BR		150	6,780	22.1	0.57	
B alone	BS	Current wave 10x60 MS Voltage wave 11x60 MS					Collapse of voltage on front and crest of oscillograms BS, BT, and BU. See oscillogram BT, figure 3. In these tests the ground around the rod was blown up and sparking on fence noted
	BT		134	5,000	26.8	0.60	
	BU		114	4,100	27.8	0.62	
	BV		93.6	2,880	32.5	0.72	
	BW		71.8	1,950	36.8	0.82	
	BX		49	1,310	37.4	0.83	
	BY		25	660	38.0	0.85	
	BZ		25	660	38.0	0.85	
B and D in parallel	CA	Current and voltage waves 10x44 MS	20.4	1,000	18.8	0.84	Ditto
	CB		41.5	2,270	18.3	0.82	
	CC		60.5	3,200	18.9	0.84	
	CD		78.0	4,480	17.4	0.78	

* In these tests the impulse generator arrangement consisted of three, 100 kv, 5 microfarad capacitor banks in series capacitance and inductance of test circuit were respectively 1.667 microfarad and 210 microhenrys. No series resistance inserted in generator (figure 1).

** Avg megger readings (table III) used to calculate ratio in column 7 above.

*** Positive polarity.

current (crest) of the characteristic the ratio does not increase more than 15 per cent at a current (crest) half that value. It is of interest to note that the crest voltage developed precedes the crest current one or two microseconds. As the current recedes on the tail of the wave, the resistance increases (table V). A similar analysis at the lower currents on the front was not possible on account of the superimposed oscillations present in this part of the oscillograms.

The process of the variation of resistance with the current discharge becomes more apparent from the ratio of the impulse to the 60-cycle resistance during the discharge, when referred to the characteristic of figure 4. The ratios of typical oscillograms (table V) are plotted in figure 5 along with the characteristic. Consider oscillograms *AW* and *BR*. As indicated by the arrows in figure 5, as the current rises on the front and approaches crest, the ratio follows the characteristic in a downward trend. When the current reaches crest and then recedes on the tail, the ratio retraces back under the curve traced for the rising part of the current. With further drop of the current the ratio continues to rise, following the characteristic upward. As the case of oscillogram *AS* shows, impulse currents of lower amplitude likewise trace paths that follow near along the characteristic.

While the nature of the oscillograms does not permit complete analysis from the beginning of the front (first few microseconds), yet it is clear from the foregoing that the mechanism of the impulse current discharge for the grounds tested is as follows. The ratio of the impulse to the 60-cycle resistance as the current rises on the front follows in good measure the characteristic (figure 4), down to the value corresponding to the crest current which lies on the characteristic. As the current recedes on the tail the ratio traces a loop under the characteristic for an impulse of high current. Apparently ionized paths or similar effects established by the discharge account for the relatively constant resistance at currents of the discharge above fifty per cent of the crest. As the current drops further, the ratio swings upward with the characteristic. As the lowest current values are reached, a residual voltage may even be present (see *AX* in figure 3).

Though the voltage of driven grounds is usually considered as a resistance drop, some inductance drop is present also. In most cases, however, the inductance of the ground proper is practically unimportant, unless the current rises or recedes unusually abruptly or in the case rods are driven to considerable depth. For each of the driven rods employed in this investigation, the inductance is approximately three microhenrys and even then only a part is effective since the current diminishes along the rod. The time constant (L/R) of the grounds is then less than 0.1 microsecond. Thus for a current rising exponentially to crest in five microseconds, the ohmic drop (Ri) at 2.5

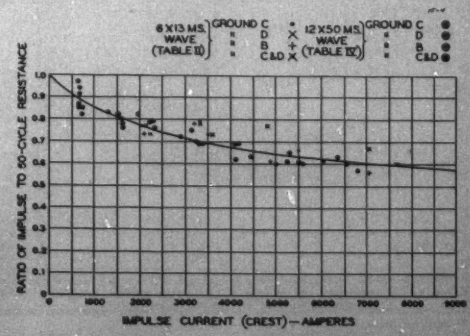

Figure 4. Characteristic of driven grounds: ratio of impulse to 60-cycle resistance versus impulse current (crest)

microseconds is 97 per cent of the impedance drop ($Ri+Ldi/dt$) and as the wave progresses beyond the two merge together since the inductive drop practically disappears. On the other hand it should be amply clear that the inductive effect of leads or in the tower structure that connect the ground proper to the point of incidence of the lightning stroke may be a factor of primary importance in lightning protection.

VII. Discussion of Results

The characteristic of figure 4 applies for a soil of medium resistivity, that is a soil consisting largely of clay with some gravel, etc. The same rods driven in other soils would likely be governed by curves of the same general character, but of different slope. Towne in his investigation[7] on 0.84-inch diameter pipes driven into loose, gravelly soil (artificial fill) obtained ratios from 0.80 to 0.34 for currents (30 x 120 microsecond wave) well under 1,000 amperes. A single ten-foot driven-pipe ground which measured 82 ohms on 60-cycle had a resistance of 50 ohms at 660 amperes—that is a ratio of 0.61. McEachron, Hemstreet, and Rudge in their field tests[8] reported for a pipe driven into the ground, which measured 180 ohms with the megger, a ratio of 0.67 at 550 amperes—the highest impulse current applied. For a 1.3 inch pipe driven four feet into natural soil consisting largely of clay, Norinder found a ratio of 0.76 corresponding to a current of approximately 1,000 amperes. It is of interest to note that in his other tests[8] where the impulse resistance was determined for both positive and negative polarities, the difference found practically was small. In this investigation (tables II and IV) positive impulse currents were applied. In short, it is clear that characteristic curves similar to figure 4 for other typical soils such as sand, etc., obviously are desirable.

Future investigations on high and low resistivity soils may furthermore shed light also on the physical processes that determine the decrease in resistance with increase in current. The present explanation, borne out by this and the investigations cited, is that "the decrease in resistance is probably due to high-resistance contacts between the more conducting particles of soil, at or near the surface of the electrode, which are bridged over by arcs or sparks when sufficient voltage is applied." For instance, the resistivity of the soil at the low 60-cycle currents for grounds *C* and *D* (table III) in the order of 7,500 ohms per cubic centimeter. On the basis of this resistivity the voltage gradient at the rod, when discharging an impulse current of 10,000 amperes (crest), would be $10{,}000 \times 7{,}500/\pi \times 90 \times 6.45$, i.e., 41 kilovolts per centimeter. It is doubtful whether grounds could sustain gradients of this magnitude at all without breakdown. As a matter of fact, from figure 4, the average resistivity of the soil at 10,000 amperes is 0.55 the 60-cycle value to which there corresponds a gradient of 22.5 kilovolts per centimeter. Actually the effective resistivity of the soil at the rod is even less, and the voltage gradient at the rod is correspondingly lower. Studies of the gradients developed should contribute to a better understanding of driven grounds.

Another factor which determines the characteristic of grounds is the size, form, and arrangement of the electrode. Besides rods and pipes, other common types

Table V. Resistance (R) of Grounds at Various Times (T) of Impulse Discharge

T (MS)	E (Kv)	I (Amps)	R (Ohms)	T (MS)	E (Kv)	I (Amps)	R (Ohms)
Driven Ground D (alone)							
	Oscillograms AS				**Oscillograms AW**		
4	46.8	1600	29.3	4	108.8	4100	26.1
6	58.5	1990	29.4	6	133	5115	26.0
8	65.8	2180	30.2	8	143.8	5640	25.5
10	69.5	2270	30.6	10	150.5	6080	24.8
12	70.5	2300	30.7	12	153.8	6200	24.8
16	70	2280	30.7	16	152.1	6270	24.3
20	66.9	2160	31.0	20	146.2	6140	23.8
30	56.8	1820	31.2	30	123	5310	23.2
40	46.8	1470	31.8	40	97.8	4030	24.3
50	38.4	1200	32.0	50	76.0	2880	26.4
60	33.4	1025	32.6	60	63.5	2240	28.4
					Oscillograms AX		
				20	145	6400	22.6
				40	96.1	4160	23.1
				60	58.5	2120	27.8
				80	36	960	37.4
				100	24	545	44.0
Driven Ground C (alone)				**Driven Grounds B and D (in parallel)**			
	Oscillograms BB				**Oscillograms CD**		
4	76	3010	25.2	4	46.6	2820	16.5
6	93.3	3585	26.0	8	68.8	4040	17.0
8	103.5	4100	25.0	10	74.5	4350	17.1
10	108.3	4225	25.6	12	77.8	4510	17.2
12	109	4415	24.7	16	79.0	4580	17.3
16	107	4415	24.4	20	75.5	4480	16.9
20	102.2	4255	24.0	30	62.1	3520	17.7
30	86.1	3715	23.2	40	45.3	2560	17.9
40	67	2890	23.2	50	32.0	1600	20.0
50	52.9	2240	23.6	60	24.4	1153	21.2
60	43.5	1865	26.2				
Driven Grounds C and D (in parallel)							
	Oscillograms BR				**Oscillograms BN**		
4	107	4410	24.3	4	46.8	1538	30.4
8	142.5	6010	23.7	8	64.5	2080	31.0
10	148.5	6400	23.2	10	68.5	2210	31.0
12	150	6720	22.4	12	68.8	2240	30.7
16	147.8	6790	21.8	16	67.1	2210	30.4
20	141.8	6720	21.1	20	63.8	2115	30.2
30	117	5760	20.3	30	54.8	1890	29.0
40	90.1	4350	20.7	40	44.8	1508	29.5
50	68.1	3200	21.3	50	35.8	1150	31.0
60	55.4	2430	22.8	60	30.8	960	32.0
70	45.4	1760	24.7	70	26.1	800	32.6

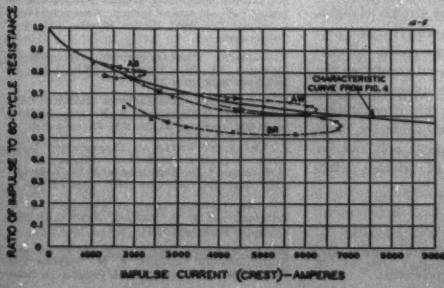

Figure 5. Variation of "impulse resistance to 60-cycle resistance" ratio during impulse current discharge compared with characteristic (figure 4)

Minimum Insulation Level for Lightning Protection of Medium-Voltage Lines

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LIGHTNING protection of wood pole lines is a problem of wide interest among operating companies. It is therefore timely to cite the experience of the Philadelphia Electric Company during the six year period, 1935–40, in successfully renovizing its 13 and 33 kv wood pole lines to reduce trouble.

In 1935 this company was faced with the problem of determining how to materially reduce lightning trouble on a variety of pole top configurations at a minimum of expense. It had been shown by Andrews and Stroup[1] that wood insulation could be employed effectively. However, no information was available to indicate what reduction in trouble could be obtained for various increases in insulation. The high ridge pin configuration proposed by these authors, while reported to be very effective, could not be applied to many of the existing line structures without making major changes in construction at considerable expense. There was therefore need for an investigation into the degree of protection afforded by lesser amounts of insulation. With this problem in mind, the author set out to make a detailed investigation of the performance of the various types of structures and to correlate their insulation strength with their rate of trouble.

It was discovered from these correlations that substantial reductions in trouble occurred with increases in insulation strength up to a certain level and that equal increases above this level were much less effective. It was evident, therefore, that the greatest reduction in trouble, at least cost, could be obtained by improving those structures which were below the indicated level. As the result of these findings, minimum insulation levels were adopted for both the 13 and 33 kv systems and used as a basis for renovizing the lines. The levels adopted were somewhat below the insulation strength of the high ridge pin construction proposed by Andrews and Stroup.

Besides establishing a minimum insulation level on which to base construction practice, the data obtained were also found very helpful in predicting what reduction in trouble might be obtained from construction changes and thereby aided in justifying the expenditure required.

This paper describes the procedure followed in determining the susceptibility to lightning trouble of pole line structures of various insulation strengths, indicates what changes were made to structures below the required minimum level and shows what reduction in trouble was obtained by these changes on the 13 and 33 kv systems.

Paper 41-14, recommended by the AIEE committee on power transmission and distribution and presented at the AIEE winter convention, Philadelphia, Pa., January 27–31, 1941. Manuscript submitted July 20, 1940; made available for preprinting November 28, 1940.

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1. For all numbered references, see list at end of paper.

Description of Systems

The 13 kv lines investigated were those in Philadelphia. They are three wire three-phase circuits with the neutral grounded through a four ohm resistor at the generating stations and through a grounding transformer at one substation. Although operated as radial circuits, they form a network over the city with numerous breakdowns to each other through pole top air break switches. These lines have a total length of 125 circuit miles, and an average length per circuit of 2.6 miles.

The 33 kv lines are in the suburban territory covering an area of approximately 1,400 square miles surrounding Philadelphia. They are three wire three-phase circuits, with the neutral solidly

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of grounds which serve to conduct lightning currents into the earth, are the footing of transmission-line towers and of other structures such as are found at substations, etc. In general, it appears from the preceding considerations and the test data that electrodes which contribute inherently to lower the current density in the soil are likely to influence the characteristic in a direction towards a more constant resistance with increase in current. The practical usefulness and basic importance in establishing characteristic curves for typical forms of ground electrodes need not be emphasized. Through such an approach the problems presented from grounds can be rationalized more readily and the value derived from grounds assessed in a more quantitative measure. An effective ground means greater safety in protection and an improved ground may mean reduced insulation or insulation clearances with the resulting benefit of reduced costs.

VII. Summary

This investigation presents test data on the impulse and 60-cycle characteristics of common rods driven in natural soil (largely clay composition). It sums up and analyzes the results in the characteristic curve of the ratio of impulse to 60-cycle resistance for impulse currents that represent conditions ranging from a traveling surge to direct strokes of lightning. The basic reasons for the performance of grounds to impulse currents as they do are pointed out insofar as the experimental data and observations permit to do so. From this investigation the desirability of establishing the characteristic for other typical soils and for other common types of grounds (electrodes) is apparent.

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grounded at two points centrally located on the system. These lines are primarily connecting links between the suburban 33 kv-4 kv substations and have a total length of 460 circuit miles and an average length per circuit of 14.2 miles.

Basis for Protection

Experience on the lines of the Philadelphia Electric Company had shown that power arcs resulting from lightning flashovers were the principal source of trouble and that lightning itself seldom caused more than slight splintering of the pole or crossarm. It was concluded, therefore, that a good basis for protection would be one which minimized the chances for power arc formation. The method adopted was to lengthen the initial arc-over paths along the pole and crossarm by increasing the insulation between phases and between phase and ground.

In determining the insulation strength of the various types of structures it appeared desirable from the above experience to base it on factors directly influencing power arc formation. Two factors which appeared predominant were the length of insulation in the arc-over path and the 60 cycle voltage across the path. Accordingly, these terms were used as a basis for measurement of insulation strength.

Measurement of Insulation Length

At the beginning of this investigation, field surveys were conducted which showed that both the 13 and 33 kv systems had a large variety of pole top arrangements, resulting in a wide range of insulation lengths along the arc-over paths between phases and between phase and ground. It was therefore necessary to make all comparisons of power arc trouble on the basis of individual structures rather than on miles of line, as is frequently done. Accordingly detailed information was obtained for each pole indicating such things as length of crossarm, type of insulators and braces, location of line wires, guys, ground wires, and other pertinent data. From these data the length of insulation in the arc-over path between phases and between phase and ground was determined for each structure. In all, approximately 20,000 poles were investigated.

In each case the arc-over path was considered as being along the surface of the pole or crossarm rather than directly between wires in air.[1] The length of insulation in the arc-over path was taken as the sum of the porcelain and wood insulation lengths. Parts of the crossarm or pole shunted by metallic hardware were excluded. The insulation length assigned to each pin type insulator was its wet arc-over distance as given by the manufacturer's catalog, while for a string of suspension insulators their insulation length was taken to be the wet arc-over of one unit plus the distance between centers of successive additional units. This was done because this distance is the length of the arc-over path after the lightning has flashed over the string.

The measurement of length of insulation in the arc-over path is illustrated in figures 1 and 2. In figure 1 the total length of insulation from phase *A* to phase *B* is 84 inches, and from phase *A* to ground *G* is 49 inches. The wet arc-over distance for each 33 kv pin type insulator is six inches. In figure 2 the suspension insulators are ten inches in diameter, have a distance between centers of $5^3/_4$ inches, and a wet arc-over per unit of approximately four inches. Adding the four inch wet arc-over distance to four times $5^3/_4$ inches (the distance between centers of insulators) gives a total arc-over distance of 27 inches for the five-unit string. This added to the 24 inches of wood on the pole gives a phase to ground insulation length of 51 inches.

Unit of Insulation Strength

For simplicity, it was found desirable to combine the two factors, insulation length and 60 cycle voltage, into a common unit of insulation strength called "inches per kv." This unit is simply the length of insulation in the arc-over path divided by the operating voltage. When determining the phase to phase insulation strength the length of insulation between phases is divided by the line to line voltage, whereas for phase to ground strength the length of insulation between phase and ground is divided by the line to ground voltage. Referring to figure 2, the insulation strength between phases *A* and *B* is 3.1 inches per kv, or 102 inches divided by the line to line voltage, 33 kv. Between phase *A* and the guy it is 2.7 inches per kv, or 51 inches divided by line to ground voltage, 19 kv. For this structure the minimum is 2.7 inches per kv. All comparisons in this investigation were based on the minimum insulation strength of each structure expressed in inches per kv, irrespective of whether it was phase to phase or phase to ground. This was done because experience had shown that phase to phase as well as phase to ground strengths are important in the control of power arc formation.

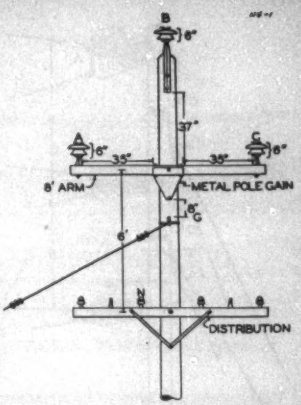

Figure 1. 33 kv high ridge pin structure

	Insulation Length Inches	Insulation Strength Inches Per Kv
A to *B*	84	2.6
A to *C*	82	2.5
A to *G*	49	2.6
B to *G*	51	2.7

Using "inches per kv" as the basis for measurement has the advantage over using lightning flashover data of employing two readily measurable factors, insulation length and 60 cycle voltage, which directly govern the tendency for formation of power arcs following lightning flashover. Taking these factors into account appears to meet in part the need expressed by Andrews[2] in 1938 for data on factors influencing power-follow in addition to lightning flashover data. Factors such as magnitude of short circuit current, circuit tripping time, wind and rain also have some influence, but inclusion of them was beyond the scope of this investigation. There is still need for more study of the influence of all these factors on power arc formation.

It should also be appreciated that the results given here are based on empirical data and that investigations under controlled laboratory conditions with lightning surges superimposed on the 60 cycle voltages would be of considerable value.

Minimum Insulation Level

Having determined the minimum insulation strength in "inches per kv" for each structure from field surveys, the next step was to classify structures according to their strength. The annual rate of trouble experienced in power arc faults per 100 circuit structures was then determined for each group and a susceptibility curve

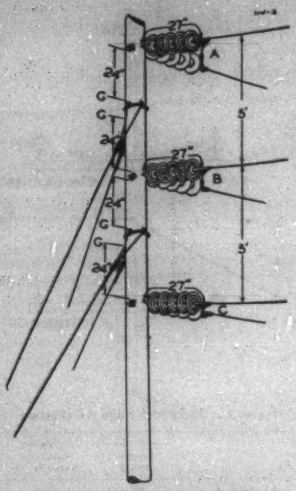

Figure 2. 33 kv corner pole structure

	Insulation Length Inches	Insulation Strength Inches Per Kv
A to B	109	3.1
A to G	51	2.7

plotted for each system of the two voltage classes studied. Susceptibility curves based on the composite results for the five year period 1935–39 are shown in figure 3. These indicate that as the insulation strength increases up to a certain level, the rate of power arc faults decreases quite rapidly, whereas further increases beyond this level are much less effective. The fact that the 13 and 33 kv curves do not parallel each other is probably due to the dissimilarity of the two systems in regard to location, number of structures in a given insulation strength class, storm exposure, and other variables referred to in the preceding section of this paper. The significant thing is that both curves show the same general trend and permit selection of a minimum insulation level on which to base construction practice.

Based on susceptibility curves developed earlier in this investigation and similar to those in figure 3, a minimum insulation level of two inches per kv was adopted for the 33 kv system and 3.5 inches per kv for the 13 kv system. These points are just below the knee of the curves. Also, much of the improvement work could be carried on fairly economically up to these levels with substantial reductions in trouble. A level above two inches per kv for 33 kv lines would have been difficult to obtain on many existing structures without replacing the present poles with larger ones. Also, a level above 3.5 inches per kv for 13 kv lines would have required increasing the insulation strength on a large number of low ridge pin poles which were already 3.5 inches per kv, and which had been changed from flat top to this configuration prior to this investigation. The principal aim of the improvement program was to raise the insulation strength of structures which were below the adopted minimum to that value or better. Just how much insulation strength is required for immunity to power arc trouble is not known. However, thus far with 2,300 structure years of experience no trouble has occurred on 13 kv high ridge pin configuration in Philadelphia having a minimum insulation strength of from 6.5 to 7 inches per kv. For the 33 kv system there appears to be no practical value of insulation which will entirely prevent power arc trouble.

Besides being of value in adopting a minimum insulation level the susceptibility curves provide a means for predicting what reduction in power arc faults may be expected by increasing insulation strength from one level to another. Such predictions are of value in determining whether proposed changes on the lines may be economically justified. Being based on five years' experience on a large number of circuit structures, the curves in figure 3 are believed to closely approximate the average annual performance that may be expected for various levels of insulation strength.

In the development of the susceptibility curves power arc faults were selected on the following basis. Any evidence of power arc damage to wires or insulators on a given structure of a single circuit line was classed as a single case of power arc trouble, irrespective of the number of phases involved. Similarly evidence of power arc damage to two circuits on the same structure was classed as two cases of trouble. This classification was necessary because both single and twin circuit structures were included in the analysis. For the same reason it was necessary to place the rate of trouble on a "circuit structure" basis rather than just on a "structure" basis. Thus the number of circuit structures on a single circuit line was taken to equal the number of poles in that line, whereas the number of circuit structures in a twin circuit line was double the number of poles.

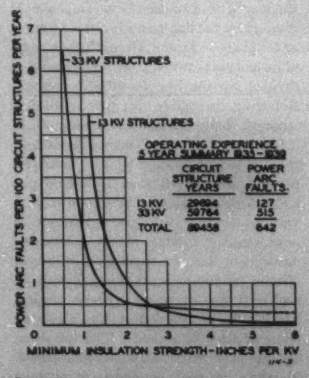

Figure 3. susceptibility of 13 and 33 kv aerial circuit structures to power arc damage following lightning flashover

Line Improvements

By the close of the 1940 lightning season, the 13 kv line improvement work in Philadelphia had been virtually completed, with approximately 95 per cent of the circuit structures having an insulation strength of 3.5 inches per kv or better. Similarly, improvements to the 33 kv lines had brought about 75 per cent of that system up to two inches per kv or better.

The principal changes on the 13 kv lines consisted of (*a*) removal, relocation or insulation of guys, (*b*) replacement of metal with wood braces, (*c*) use of porcelain or wood sections in the horizontal and vertical operating bars of gang operated air break switches, (*d*) rebuilding of deadends and corners, and (*e*) changeover from low ridge pin to high ridge pin configuration by lowering the crossarm or use of wood pole extensions. These changes were made to obtain additional wood insulation between phases and between phase and ground.

As already mentioned, much of the 13 kv construction in Philadelphia had been changed over from flat top to low ridge pin, figure 4, prior to this investigation. However, where pole space permitted lowering the crossarm two to four feet at little cost, this was done to obtain high ridge pin construction. In replacing old poles and in building new lines, the four foot high ridge pin configuration has been used. This construction gives approximately equal insulation strength between phases *A* and *B*, *B* and *C*, and *C* and *A*. It also has about the same dimensions as the 33 kv high ridge pin shown in figure 1 and permits ready conversion to 33 kv operation by merely changing to larger insulators. High ridge pin configuration has been applied to a

number of 13 kv pole top switches in Philadelphia.

Changes on the 33 kv system were similar to those cited above. However, much of the improvement to this system has been obtained through relocation or removal of guys and removal of overhead and vertical ground wires. Whatever benefit may have been obtained from the overhead ground wires was nullified by their iron supports and vertical ground leads shunting out the wood pole insulation and thus permitting a ready path for formation of power arcs. Breakage of the overhead ground wires in storms was also another cause for their removal. Pole gains of the type shown in figure 1 have been used extensively to replace metal braces. Isolated groups of steel towers in the wood pole lines at such places as railroad crossings have been improved by replacing metal arms with wood or by adding suspension insulator units up to a total of seven per string. Pole top switches with steel supporting frames and steel operating rods have been particularly susceptible to trouble. Many of these have been rebuilt, using wood supporting members and wood sections in the operating bar. A new design 33 kv vertical switch using post type insulators mounted on two rotating wood uprights is shown in figure 5. This has four feet separation between phases and an insulation strength of two inches per kv. Also on new lines, construction of the type shown in figures 1 and 2 is being used.

Because guys have been one of the chief sources of lightning trouble on both the 13 and 33 kv systems, it is well to consider some of the remedies and certain conditions that should be looked for when trying to obtain additional wood insulation. In most instances improvement has been

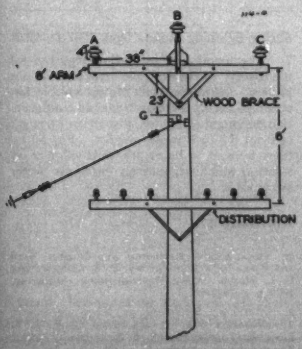

Figure 4. 13 kv low ridge pin structure

Figure 5. 33 kv vertical switch

obtained by lowering or raising guys to the position on the pole which provides the desired amount of wood insulation without sacrificing mechanical strength. Often side guys were found attached to stub poles, which in turn were guyed to ground. Separation of the guys on the stub pole in the manner shown in figure 6 was frequently done to gain wood insulation. This diagram shows an air clearance of nine inches between the guys on the stub so that lightning flashover would be more likely to go across the 15 inches of wood pole rather than across the air gap. If flashover should occur across the air gap, the power arc which followed would therefore be shorter and not so readily interrupted as if flashover had originated across the 15 inches of wood. As a basis for determining desirable air clearance for guys, one inch of air path was taken approximately to equal two inches of wood on an impulse strength basis. Where practical, therefore, an effort was made to have the air gap distance a little greater than half the length of wood insulation.

Guys were sometimes found too close to line wires, or were brought down at such a sharp angle as to shunt out much of the wood pole insulation by passing too close to a through bolt holding the line suspension insulators as in the case of corner poles. Also, guys which were supposedly insulated from ground were found close to or in contact with lightning arrester ground wires, pipes and conduits on the pole, or to other grounded objects. Tail guys used in dead-ending the three phases of a line were found to converge on a common point of attachment. This condition permitted phase to phase short circuits through the guys when flashover of the dead-end insulators occurred and

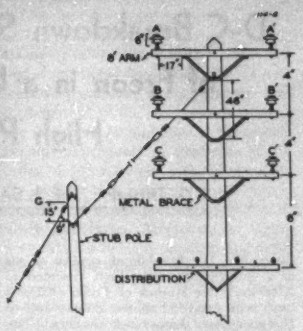

Figure 6. 33 kv twin circuit structure

was remedied by obtaining vertical separation of the three guys on the attachment pole. Where guys could not be effectively relocated, wood guy strain insulators equipped with arcing horns have been used in a number of instances.

In this study the conventional porcelain guy insulators were assumed to provide no insulation strength because of their small wet arc-over distance.

Performance

While the susceptibility curves indicate what reduction in rate of trouble can be obtained on individual structures through increases in insulation strength, it is of interest to note what over-all decrease in line interruptions and power arc faults has been obtained through the various changes that have been made.

On the 13 kv system in Philadelphia line interruptions during lightning storms decreased from 55 per 100 circuit miles in 1935 to 14 in 1940, a reduction of 75 per cent. Similarly, 33 kv line interruptions decreased 62 per cent, or from 45 to 17 per 100 circuit miles from 1937 to 1940, in which period almost all of the improvement work was done. While variations in the severity of the lightning seasons affect such comparisons, it is believed that the reductions in line interruptions given above were largely due to the line improvements.

Approximately the same percentage reduction in power arc faults as in line interruptions were obtained. On the 33 kv lines cases of pole splintering without accompanying power arc trouble showed an appreciable increase during the period of line renovation. This was expected and further confirms the results showing the value of increased insulation in reducing power arc trouble.

There has been no apparent increase in

D-C Breakdown Strength of Air and of Freon in a Uniform Field at High Pressures

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Synopsis: D-c breakdown studies of air in a uniform field have been extended to 1,000 kv. D-c studies of Freon (CCl_2F_2) have been extended to over 350 kv and to 135 pounds per square inch absolute. The departure from Paschen's law at the higher values of pressure times gap is noted. The mechanisms which account for the higher insulating strength of such gaseous compounds as CCl_2F_2 are outlined and their possibilities and limitations in the insulation of high-voltage apparatus are briefly discussed.

Introduction

IT has long been recognized[1] that the insulating strength of air and other gases in a uniform field increases with the pressure. The classical analysis of the voltage-breakdown mechanism and its dependence on pressure and other properties of the gas was made by Townsend in 1903.[1] This explanation was based on the ionization of the interelectrode gas by both electron and positive-ion collision—a process which Townsend showed would become cumulative when the positive ions produced by the electrons moving toward the anode under the influence of the field become capable, by their ionizing collisions, of producing an even greater number of new electrons. Since that time, Townsend's second coefficient β has been reinterpreted to include various other mechanisms which contribute regeneratively to the charged particles in the interelectrode space. Among these are photoelectric emission, secondary electron emission due to positive-ion impact at the cathode, photo-ionization in the gas, and ionization by excited atoms and by multiple collisions. In addition, it has become evident that any explanation of high-pressure breakdown must also take into account the several processes of ion removal and the important influence of space charge and the myriads of tiny self-healing electron avalanches in modifying the electric field.[2] Recognition of these various ion-producing, ion-removing, and field-modifying mechanisms has clarified the general picture of breakdown in gases but at the same time has shown it to be too intricate for full quantitative description. Because of this complexity, knowledge of gaseous insulation continues to depend to a large extent on the experimental determination of the breakdown strength and pre-breakdown behavior of the various gases as a function of pressure and electrode geometry, and on the investigation—both under simplified and under practical conditions—of the relative importance of the several mechanisms involved in gaseous breakdown. This paper extends d-c breakdown studies in air and in Freon 12 (dichlorodifluoromethane) at high pressures and in a uniform field to higher voltages than have been reported previously, and indicates reasons for the observed departures from Paschen's law and for the relatively high insulating strength of the Freon.

Apparatus

The investigation of the breakdown of air at voltages up to 1,000 kv was made with a pressure-insulated electrostatic generator[4] developed at the Institute for the production of high-voltage X rays for medical use. The uniform gap was established by a fixed electrode of polished steel[a] attached to the high-voltage terminal and a similar but movable electrode connected to the tank. The diameter of these electrodes was six inches, and their shape was such that in the central gap area the electric field was a maximum and substantially uniform for gaps up to one and one-half inches. The voltage was measured by a generating voltmeter[5] with an estimated error of less than two per cent.

Most of the studies of the breakdown of Freon were made in a 13-inch-diameter

Paper 41-9, recommended by the AIEE committee on basic sciences and presented at the AIEE winter convention, Philadelphia, Pa., January 27-31, 1941. Manuscript submitted September 16, 1940; made available for preprinting November 6, 1940.

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1. For all numbered references, see list at end of paper.

[a] The several grades of steel, stainless steel, brass, and aluminum give about the same results as electrode materials, the breakdown voltage at higher pressure and gradient being dependent primarily on the smoothness and freedom from contamination of the surfaces rather than on the nature of the metal itself.

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substation lightning trouble on the 13 and 33 kv systems due to the increase in line insulation.

Summary and Conclusions

1. On the 13 and 33 kv wood pole lines of the Philadelphia Electric Company power arcs following lightning flashover were the principal source of trouble, while lightning itself seldom caused more than slight splintering of the pole or crossarm.

2. The chances of a power arc forming after lightning flashover depend upon the 60 cycle voltage and length of insulation. These factors were combined into a common unit of insulation strength called "inches per kv."

3. Increases in insulation strength up to approximately two inches per kv for 33 kv lines and 3.5 inches per kv for 13 kv lines were found to be much more effective in reducing trouble than increases beyond these limits.

4. These limits were adopted by the Philadelphia Electric Company as a practical minimum of insulation strength on which to base construction practice in renovizing its lines.

5. Improvements to obtain the minimum insulation strength of 3.5 inches per kv or better on the 13 kv system in Philadelphia are believed largely responsible for a 75 per cent reduction in line interruptions during lightning storms from 1935 to 1940.

6. Similar improvements to obtain the minimum insulation strength of two inches per kv or better on the 33 kv system are believed largely responsible for a 62 per cent reduction in line interruptions during lightning storms from 1937 to 1940.

7. The amount of insulation required for immunity to power arc trouble is not known. However, thus far no trouble has occurred on 13 kv high ridge pin configuration having a minimum insulation strength of from 6.5 to 7 inches per kv. For 33 kv there appears to be no practical value of insulation which will entirely eliminate power arc trouble.

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1. TRANSMISSION RESEARCH AND DESIGN WITH THE FIELD AS A LABORATORY, F. E. Andrews and C. L. Stroup. AIEE TRANSACTIONS, volume 49, 1930, pages 959–68.

2. LIGHTNING STRENGTH OF WOOD IN POWER TRANSMISSION STRUCTURES, Philip Sporn, J. T. Lusignan, Jr., discussion by F. E. Andrews. AIEE TRANSACTIONS, volume 57, 1938 (July section), page 410.

steel pressure tank[4] provided with a Textolite high-voltage bushing for 500 kv. External heaters were applied to the tank so that vapor pressures up to 140 pounds per square inch absolute could be maintained. The high-voltage source was a 500-kv constant-potential electrostatic generator of the Van de Graaff type. The voltage was measured with an error of less than three per cent, using a calibrated spiral-line type of high resistance.

Insulating Strength of Compressed Air in a Uniform Field

Figure 1 gives the d-c breakdown voltage of dry air in a uniform field for a range of pressures from 1 to 13 atmospheres and electrode separations up to one and one-half inches. This figure also gives similar data taken in the same apparatus on the breakdown of Freon at pressures up to 45 pounds per square inch absolute, and for voltages up to 500 kv. These Freon data are discussed later in this report. It is to be observed that at each pressure the voltage increases linearly with electrode separation. Since both the voltage and the product of pressure times gap are substantially higher than any heretofore reported, the data on compressed-air insulation are examined with reference to Paschen's law.

It was stated by Paschen[7] and it followed from Townsend's and subsequent analyses that for a given gas and a uniform field the sparking voltage is a function of the product of the interelectrode gap and the gas pressure. The more general similarity law enunciated 50 years later declares the sparking potential of a gas to remain unchanged if the physical dimensions of the electrodes and gap are changed in the inverse ratio to the change in pressure. Paschen's law has been checked at pressures ranging from the critical pressure (corresponding to minimum sparking potential) to many atmospheres, and experimenters have been generally agreed that Paschen's law holds up to gas pressures of ten atmospheres.[8] Some experimenters have measured the linear increase in the breakdown voltage across a uniform gap with gas pressure, and concluded Paschen's law to hold until departure from the linearity was found. It must be pointed out, however, that Paschen's law does not predict this linearity of voltage and pressure, though this linearity does exist over a considerable pressure range. Paschen's law predicts for a uniform field the constancy of the breakdown potential when the product of the interelectrode gap and the gas pressure is constant. In figure 2 the data in figure 1 are replotted to show the variation with pressure of the d-c breakdown voltage across a uniform field in air for constant values of pd from 10 to 240 pounds per inch. (One pound per inch = 131 millimeters Hg × centimeter.) It is seen that the relative voltage change with pressure is greater at the higher values of pd. The bulk of the recorded data lies in the realm in which Paschen's law fails, so that a slight reduction of voltage with pressure is shown even for the lowest value of pd.

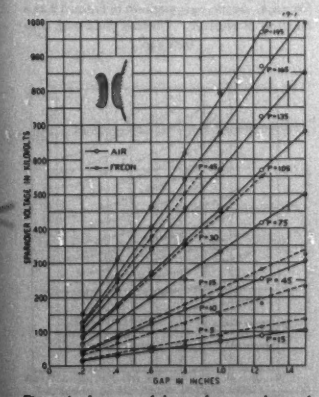

Figure 1. Increase of d-c spark-over voltage of air and of Freon 12 with electrode separation at several absolute pressures in pounds per square inch. Uniform field

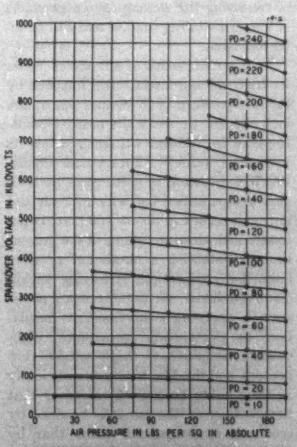

Figure 2. The spark-over voltage in air as a function of pressure for constant values of pressure times gap in pounds per inch

The decrease in the breakdown voltage with increasing pressure at the higher values of pd is not unexpected, since the higher gradients favor photoelectric and secondary emission at the cathode. The contribution of the electrode surfaces to the ionization by high field emission may become appreciable at gradients of the order of 10^6 volts per inch, particularly for surfaces that have been inadequately cleaned and conditioned by sparkover or other discharges. Moreover, at higher pressures the reduced mobility and diffusivity of the ions in the interelectrode gap increase the field distortion due to space charge and hence upset the ideal considerations upon which Paschen's law is based. Analysis of other data indicates that departure from Paschen's law begins at values of pd of about two pounds per inch. Differences in the experimental values of pd at which Paschen's law has been observed to fail are probably due largely to variations in electrode conditioning, which has a marked effect on the breakdown value, as well as to variations in the experimental arrangements such as size, shape, and smoothness of the electrodes, proximity of the chamber walls, and voltage wave shape.

Insulating Strength of Freon at High Pressures

That certain compounds in the gaseous state, notably those which contain chlorine, fluorine, or other electronegative atoms, have a higher insulating strength than air or the other permanent gases, has been known since the investigations of Natterer and others in 1898. A number of studies have been made of the insulating properties of Freon 12[9]—a gas which was developed primarily for use as a refrigerant. As seen from figure 1, Freon can insulate a given d-c voltage at about one-third the pressure required with air. It was felt desirable to extend the breakdown studies of Freon to higher pressures and voltages, since the full advantage of such special compounds over air is realized only if they can be used at essentially the same pressures. Figure 3 shows the breakdown strength of Freon in a uniform field for pressures from 5 to 135 pounds per square inch absolute, and with constant potentials up to 350 kv. Since the vapor pressure of this compound at 70 degrees Fahrenheit is about 85 pounds per square inch absolute, the higher pressures were obtained by heating the chamber the required amount. Care was necessary to prevent condensation of the gas on the electrodes, such condensation lowering the voltages which

could otherwise be obtained. A small amount of preliminary sparking was found desirable to condition the electrode surfaces, but the decomposition of the Freon resulting from sparking gradually led to sufficient deposition of carbon on the electrodes to lower the breakdown voltage. This effect was most noticeable at the higher pressures, in which the energy of the discharges was greatest. In general it was found that the behavior of Freon was more erratic the higher the pressure, probably because of the changing nature of the electrode surfaces through carbon deposition and the increasingly high field emission from these surfaces. However, with uniform fields the breakdown gradient continued to increase with pressure, as is shown by the curve in figure 4 for a 0.2-inch gap. Gradients of over 1,200 kv per inch were insulated at 135 pounds per square inch absolute, and there was evidence that with careful electrode conditioning the values indicated by this curve might be increased by about 15 per cent. Figure 5 shows the dependence of the breakdown potential of Freon upon pressure for constant values of pressure times gap. The departure from Paschen's law, as indicated by the slope of these curves, begins when pd is greater than two pounds per inch and increases with the higher values. That this departure progresses more rapidly than in the case of air is probably due in part to the influence of inadequately conditioned electrode surfaces.

Reasons for the Higher Insulating Strength of Freon

The higher insulating strength of Freon and similar compounds, as compared with air and other permanent gases, may be ascribed primarily to two causes. The one is the relatively large number of inelastic impacts which an electron may make in such gases[10] with consequent loss of energy and ionizing power; the other is the electron affinity of the electronegative particles in the gas, such as the chlorine and fluorine atoms. This results in the removal of free electrons from the gas with the accompanying formation of relatively inert negative ions. By the former mechanism, such electrons as are created by ionization in the gas are retarded in their accumulation of ionizing energy by the frequent loss of energy on impact. Through the second mechanism the electrons, which are the most effective ionizing agents, are rendered impotent by attachment to heavy electronegative particles.

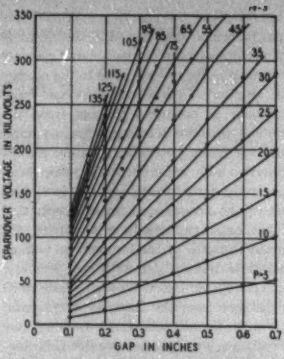

Figure 3. Increase of the d-c spark-over voltage of Freon 12 with electrode separation for absolute pressures from 5 pounds to 135 pounds per square inch. Uniform field

An obstacle to the immediate widespread use of Freon or other such compounds is the gradual decomposition of the gas under the influence of corona and sparkover. In the experimental use of Freon in the pressure-insulated electrostatic generator, although some decomposition of the gas occurred, no impairment of the insulating strength of the gas or of the solid insulation in the chamber, and very little corrosion of the metals was observed after about ten hours. Since there is evidence, however, that the long-time effects of this chemical instability may be serious, this problem and methods of removing the decomposition products of Freon are being studied and will be reported later.

Another limitation to the use of Freon for high-voltage insulation is imposed by the low pressure of 55 pounds per square inch absolute at which the positive point-to-plane breakdown voltage reaches its maximum value.[11] This characteristic, which is common to most gases at ordinary temperatures but which for air and nitrogen occurs at about 160 pounds per square inch absolute, seems at the present time to establish a maximum pressure limit for applications involving highly distorted fields. It thus becomes necessary in applying compressed-gas insulation to electrostatic generators, high-voltage transformers, high-voltage condensers, and the like, to secure sufficiently uniform fields throughout in order that the pressure of the gas may be fixed by economic considerations rather than by an inherent limitation in its insulating properties.

When it is considered that in many high-voltage applications, such as the insulation of electrostatic generators, any increase in the dielectric strength of the gas is reflected (in the limit) as the cube in reduced volume of apparatus, the great practical importance of such superior insulating gases as Freon is realized. It is not unlikely that compounds will become available which show even greater chemical stability than Freon, and at the same time have higher vapor pressures at room temperature. Such gaseous compounds, whose use for insulation is already in a preliminary commercial stage,[12] may ultimately supplant the permanent gases and even liquid dielectrics for the insulation of high-voltage apparatus.

Acknowledgments

The authors take pleasure in acknowledging the assistance in this work of Mr. A. T. Norton, Jr., as well as of members of the WPA Medical Radiation group. The development of the pressure-insulated X-ray generator was made possible

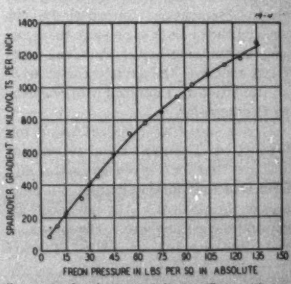

Figure 4. Spark-over gradient in Freon 12 as a function of pressure. Uniform field with 0.2-inch gap

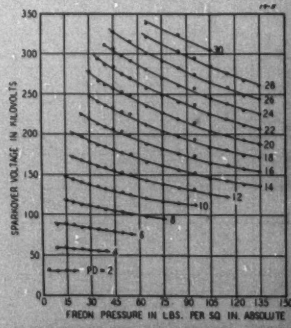

Figure 5. Spark-over voltage of Freon 12 as a function of pressure for several values of pressure times gap in pounds per inch

A Five-Figure Table of the Bessel Function $I_n(x)$

HERBERT B. DWIGHT
FELLOW AIEE

THE modified Bessel function of the first kind, $I_n(x)$, where x is a real quantity, is of widespread application, but it is of particular interest to electrical engineers, since the current and voltage for a traveling wave on an electric line can be expressed as a series of these functions.

A table of these functions was published in the Report of the British Association for the Advancement of Science, 1889, pages 29–32, and has been reprinted in "Bessel Functions" by Gray, Mathews, and MacRobert. While a large number of significant figures were given, the arguments were 0.2, 0.4, 0.6, etc.* The interpolation, as used in engineering work, is somewhat easier and more according to a decimal system when arguments 0.1, 0.2, 0.3, etc., are used. Accordingly, additional values for a five-figure table have been computed, and the enlarged five-figure table is given in this paper.

In a number such as 0.0^n26053 in the table, the figure 8 represents the number of zeros before the 2.

The work of computing the new values for this table was done by students under the National Youth Administration at the Massachusetts Institute of Technology, those doing a substantial amount of work including A. L. Carpentier, D. R. Erb, S. Grunes, L. A. King, H. A. Lent, R. P. Mork, R. T. Parry, and B. H. Sexauer.

The values in the table were computed to more decimal places than have been tabulated, and the computations were checked. As a further precaution against errors, columns of differences of the final table were computed and examined for consistency, to a large extent by R. P. Mork, who used the equation

$$\Delta_4 = A - 4B + 6C - 4D + E$$

for the computation of the fourth difference Δ_4 with a calculating machine, where A, B, C, D, and E are any five successive values of $I_n(x)$. This was found to save time and work. See also the introduction to "Tables of the Exponential Function e^x," by WPA of the City of New York, A. N. Lowan, Technical Director. The use of columns of differences is a very searching method of exposing errors in a table.

More than half of the new values were computed by an interpolation method, from the original table mentioned in the second paragraph. Interpolation coefficients given in the paper "Tables and Methods of Extending Tables for Interpolation Without Differences," by George Rutledge and Prescott Crout, *Journal of Mathematics and Physics*, volume 9, 1930, were employed. These, when used with a calculating machine, were found to save considerable work, as no pencil work was needed and no columns of differences of the original table were required. For $x = 5.7$ and 5.9, Gregory-Newton interpolation coefficients were used, and this gave a comparison of the amount of work by the different methods. For the higher orders, the values were proportionately far apart and the power series in x was used, as follows:

$$I_n(x) = \frac{\left(\frac{1}{2}x\right)^n}{n!}\left[1 + \frac{\left(\frac{1}{2}x\right)^2}{1(n+1)} + \frac{\left(\frac{1}{2}x\right)^4}{1\times 2(n+1)(n+2)} + \cdots\right]$$

Equations for traveling waves on an electric line, which involve Bessel functions of the type $I_n(x)$, are given on pages 161 and 163 of chapter VII of "Principles of Electric Power Transmission," by L. F. Woodruff, and a numerical example is given on pages 163 to 165.

Acknowledgments are here made for valuable help and suggestions from Professors R. D. Douglass, P. Franklin, and L. F. Woodruff.

(For table, see next page.)

Paper 41-6, recommended by the AIEE committee on basic sciences and presented at the AIEE winter convention, Philadelphia, Pa., January 27–31, 1941. Manuscript submitted June 25, 1940; made available for preprinting October 25, 1940.

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* Large tables of $J_1(x)$ and $J_0(x)$ were given in the Report of the British Association in 1893 and 1896.

by a generous grant from the Godfrey M. Hyams Trust.

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Table of the Bessel Function $I_n(x)$

x	$I_0(x)$	$I_1(x)$	$I_2(x)$	$I_3(x)$	$I_4(x)$	$I_5(x)$	$I_6(x)$	$I_7(x)$	$I_8(x)$	$I_9(x)$	$I_{10}(x)$	$I_{11}(x)$
0	1.0000	0	0	0	0	0	0	0	0	0	0	0
0.1	1.0025	0.050063	0.0^{2}12510	0.0^{3}20846	0.0^{4}26055	0.0^{5}26053	0.0^{6}21709	0.0^{7}15506	0.0^{8}96908	0.0^{9}53836	0.0^{10}26918	0.0^{11}12235
0.2	1.0100	0.10050	0.0^{2}50167	0.0^{3}16708	0.0^{4}41750	0.0^{5}83472	0.0^{6}13900	0.0^{7}19866	0.0^{8}24829	0.0^{9}27585	0.0^{10}27582	0.0^{11}25073
0.3	1.0226	0.15169	0.011335	0.0^{2}56567	0.0^{3}21189	0.0^{4}63519	0.0^{5}15871	0.0^{6}33996	0.0^{7}63723	0.0^{8}10618	0.0^{9}15923	0.0^{10}21710
0.4	1.0404	0.20403	0.020268	0.0^{2}13467	0.0^{3}67202	0.0^{4}26845	0.0^{5}89398	0.0^{6}25524	0.0^{7}63775	0.0^{8}14166	0.0^{9}28321	0.0^{10}51478
0.5	1.0635	0.25789	0.031906	0.0^{2}26451	0.0^{3}16481	0.0^{4}82232	0.0^{5}34212	0.0^{6}12205	0.0^{7}38108	0.0^{8}10578	0.0^{9}26430	0.0^{10}60041
0.6	1.0920	0.31370	0.046365	0.0^{2}46023	0.0^{3}34362	0.0^{4}20556	0.0^{5}10256	0.0^{6}43853	0.0^{7}16436	0.0^{8}54731	0.0^{9}16406	0.0^{10}44713
0.7	1.1263	0.37188	0.063790	0.0^{2}73674	0.0^{3}64074	0.0^{4}44670	0.0^{5}25982	0.0^{6}12963	0.0^{7}56615	0.0^{8}21987	0.0^{9}76860	0.0^{10}24436
0.8	1.1665	0.43286	0.084353	0.011100	0.0^{3}11013	0.0^{4}87635	0.0^{5}58202	0.0^{6}33164	0.0^{7}16545	0.0^{8}73404	0.0^{9}29319	0.0^{10}10649
0.9	1.2130	0.49713	0.10826	0.015972	0.0^{3}17790	0.0^{4}15904	0.0^{5}11871	0.0^{6}76039	0.0^{7}42652	0.0^{8}21278	0.0^{9}95576	0.0^{10}39040
1.0	1.2661	0.56516	0.13575	0.022168	0.0^{3}27371	0.0^{4}27146	0.0^{5}22489	0.0^{6}15992	0.0^{7}99606	0.0^{8}55184	0.0^{9}27529	0.0^{10}12490
1.1	1.3262	0.63749	0.16709	0.029891	0.0^{3}40493	0.0^{4}44101	0.0^{5}40138	0.0^{6}31369	0.0^{7}21476	0.0^{8}13080	0.0^{9}71745	0.0^{10}35791
1.2	1.3937	0.71468	0.20260	0.039350	0.0^{3}58007	0.0^{4}68789	0.0^{5}68209	0.0^{6}58093	0.0^{7}43354	0.0^{8}28789	0.0^{9}17216	0.0^{10}93553
1.3	1.4693	0.79733	0.24262	0.050815	0.0^{3}80888	0.0^{4}10371	0.0^{5}11124	0.0^{6}10253	0.0^{7}82818	0.0^{8}59535	0.0^{9}38550	0.0^{10}22707
1.4	1.5534	0.88609	0.28755	0.064522	0.011026	0.0^{3}15191	0.0^{4}17520	0.0^{5}17369	0.0^{6}15095	0.0^{7}11678	0.0^{8}81382	0.0^{9}51598
1.5	1.6467	0.98167	0.33783	0.080774	0.014738	0.0^{3}21706	0.0^{4}26777	0.0^{5}28406	0.0^{6}26426	0.0^{7}21885	0.0^{8}16331	0.0^{9}11088
1.6	1.7500	1.0848	0.39397	0.099892	0.019371	0.0^{3}30356	0.0^{4}39874	0.0^{5}45060	0.0^{6}44666	0.0^{7}39424	0.0^{8}31358	0.0^{9}22606
1.7	1.8640	1.1963	0.45650	0.12223	0.025089	0.0^{3}41665	0.0^{4}58039	0.0^{5}69587	0.0^{6}73208	0.0^{7}68593	0.0^{8}57926	0.0^{9}44518
1.8	1.9896	1.3172	0.52604	0.14819	0.032077	0.0^{3}56248	0.0^{4}82798	0.0^{5}10495	0.0^{6}11677	0.0^{7}11574	0.0^{8}10341	0.0^{9}86091
1.9	2.1277	1.4482	0.60327	0.17820	0.040545	0.0^{3}74830	0.0^{4}11603	0.0^{5}15500	0.0^{6}18180	0.0^{7}19001	0.0^{8}17905	0.0^{9}15359
2.0	2.2796	1.5906	0.68895	0.21274	0.050729	0.0^{3}98257	0.0^{4}16002	0.0^{5}22464	0.0^{6}27699	0.0^{7}30442	0.0^{8}30170	0.0^{9}27222
2.1	2.4463	1.7455	0.78390	0.25235	0.062895	0.012751	0.0^{3}21754	0.0^{4}32011	0.0^{5}41388	0.0^{6}47707	0.0^{7}49600	0.0^{8}46956
2.2	2.6291	1.9141	0.88906	0.29763	0.077345	0.016374	0.0^{3}29195	0.0^{4}44923	0.0^{5}60761	0.0^{6}73288	0.0^{7}79748	0.0^{8}79029
2.3	2.8296	2.0978	1.0054	0.34922	0.094415	0.020825	0.0^{3}38722	0.0^{4}62173	0.0^{5}87785	0.0^{6}11056	0.0^{7}12565	0.0^{8}13007
2.4	3.0493	2.2981	1.1342	0.40787	0.11448	0.026357	0.0^{3}50814	0.0^{4}84966	0.0^{5}12499	0.0^{6}16408	0.0^{7}19436	0.0^{8}20876
2.5	3.2898	2.5167	1.2765	0.47437	0.13798	0.032843	0.0^{3}66033	0.0^{4}11478	0.0^{5}17560	0.0^{6}23978	0.0^{7}29557	0.0^{8}33199
2.6	3.5533	2.7554	1.4337	0.54963	0.16537	0.040786	0.0^{3}85045	0.0^{4}15342	0.0^{5}24368	0.0^{6}34560	0.0^{7}44256	0.0^{8}51648
2.7	3.8417	3.0161	1.6075	0.63463	0.19721	0.050313	0.0^{3}10863	0.0^{4}20305	0.0^{5}33437	0.0^{6}48175	0.0^{7}65319	0.0^{8}79085
2.8	4.1573	3.3011	1.7994	0.73048	0.23408	0.061686	0.013772	0.0^{3}26636	0.0^{4}45423	0.0^{5}66146	0.0^{6}95134	0.0^{7}11933
2.9	4.5027	3.6126	2.0113	0.83841	0.27666	0.075204	0.017337	0.0^{3}34648	0.0^{4}61056	0.0^{5}96163	0.0^{6}13686	0.0^{7}17762
3.0	4.8808	3.9534	2.2452	0.95975	0.32571	0.091206	0.021684	0.0^{3}44721	0.0^{4}81370	0.0^{5}13237	0.0^{6}19464	0.0^{7}26104
3.1	5.2945	4.3262	2.5034	1.0960	0.38205	0.11008	0.026957	0.0^{3}57309	0.0^{4}10754	0.0^{5}18049	0.0^{6}27388	0.0^{7}37913
3.2	5.7472	4.7343	2.7883	1.2489	0.44665	0.13226	0.033325	0.0^{3}72948	0.0^{4}14102	0.0^{5}24391	0.0^{6}38155	0.0^{7}54459
3.3	6.2426	5.1810	3.1027	1.4202	0.52054	0.15825	0.040382	0.0^{3}92274	0.0^{4}18357	0.0^{5}32690	0.0^{6}52660	0.0^{7}77421
3.4	6.7848	5.6701	3.4495	1.6119	0.60490	0.18861	0.050153	0.011804	0.0^{3}23734	0.0^{4}43470	0.0^{6}72046	0.0^{8}10900
3.5	7.3782	6.2058	3.8320	1.8264	0.70105	0.22398	0.061096	0.014512	0.0^{3}30489	0.0^{4}57384	0.0^{6}97761	0.0^{8}15207
3.6	8.0277	6.7927	4.2540	2.0661	0.81046	0.26509	0.074109	0.018055	0.0^{3}38932	0.0^{4}75232	0.0^{6}13163	0.0^{8}21034
3.7	8.7386	7.4357	4.7193	2.3338	0.93475	0.31273	0.089532	0.022356	0.0^{3}49431	0.0^{4}97992	0.0^{6}17595	0.0^{8}28859
3.8	9.5169	8.1404	5.2325	2.6326	1.0758	0.36784	0.10776	0.027554	0.0^{3}62427	0.0^{4}12686	0.0^{6}23337	0.0^{8}38293
3.9	10.369	8.9128	5.7963	2.9658	1.2355	0.43145	0.12923	0.033815	0.0^{3}78443	0.0^{4}16329	0.0^{6}30805	0.0^{8}51115
4.0	11.302	9.7595	6.4222	3.3373	1.4163	0.50472	0.15446	0.041330	0.0^{3}98099	0.0^{4}20903	0.0^{6}40379	0.0^{8}67308
4.1	12.324	10.688	7.1100	3.7511	1.6206	0.58899	0.18404	0.050322	0.012213	0.0^{4}26620	0.0^{6}52620	0.0^{8}89115
4.2	13.442	11.706	7.8684	4.2120	1.8513	0.68571	0.21863	0.061048	0.015140	0.0^{4}33734	0.0^{6}68194	0.0^{8}12609
4.3	14.668	12.822	8.7043	4.7249	2.1115	0.79656	0.25899	0.073805	0.018692	0.0^{4}42552	0.0^{6}87914	0.0^{8}16618
4.4	16.010	14.046	9.6258	5.2955	2.4046	0.92342	0.30598	0.088939	0.022989	0.0^{4}53438	0.0^{6}11277	0.0^{8}21779
4.5	17.481	15.389	10.642	5.9301	2.7347	1.0684	0.36057	0.10684	0.028170	0.0^{4}66826	0.0^{6}14397	0.0^{8}28393
4.6	19.093	16.863	11.761	6.6355	3.1060	1.2338	0.42380	0.12798	0.034400	0.0^{4}83235	0.0^{6}18297	0.0^{8}36829
4.7	20.858	18.479	12.995	7.4195	3.5233	1.4223	0.49719	0.15286	0.041869	0.010328	0.0^{6}23153	0.0^{8}47541
4.8	22.794	20.253	14.355	8.2903	3.9921	1.6369	0.58191	0.18210	0.050798	0.012768	0.0^{6}29178	0.0^{8}61087
4.9	24.915	22.199	15.854	9.2575	4.5182	1.8809	0.67967	0.21638	0.061448	0.015730	0.0^{6}36825	0.0^{8}78148
5.0	27.240	24.336	17.506	10.331	5.1082	2.1580	0.79229	0.25649	0.074117	0.019316	0.0^{6}45800	0.0^{8}99554
5.1	29.789	26.680	19.326	11.523	5.7697	2.4724	0.92185	0.30334	0.089153	0.023643	0.0^{6}57069	0.0^{8}12631
5.2	32.584	29.254	21.332	12.845	6.5106	2.8288	1.0707	0.35796	0.10596	0.028852	0.0^{6}70864	0.0^{8}15965
5.3	35.648	32.080	23.542	14.312	7.3402	3.2324	1.2415	0.42152	0.12300	0.035107	0.0^{6}87705	0.0^{8}20104
5.4	39.009	35.182	25.978	15.939	8.2686	3.6890	1.4371	0.49538	0.15281	0.042598	0.010820	0.0^{8}25236
5.5	42.695	38.588	28.663	17.743	9.3070	4.2052	1.6611	0.58106	0.18202	0.051550	0.013309	0.0^{8}31845
5.6	46.738	42.328	31.620	19.742	10.468	4.7884	1.9171	0.68031	0.21633	0.062225	0.016322	0.0^{8}39819
5.7	51.173	46.436	34.879	21.959	11.765	5.4466	2.2095	0.79511	0.25657	0.074925	0.019961	0.0^{8}48834
5.8	56.038	50.946	38.470	24.415	13.214	6.1890	2.5430	0.92771	0.30367	0.090004	0.024346	0.0^{8}60519
5.9	61.377	55.900	42.427	27.136	14.831	7.0259	2.9230	1.0807	0.35872	0.10787	0.029617	0.0^{8}74750
6.0	67.234	61.343	46.787	30.151	16.637	7.9685	3.3558	1.2569	0.42297	0.12901	0.036940	0.0^{8}92070

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Industrial Notes

Expansion Plans.—Purchase of land on which the Westinghouse Electric & Manufacturing Co. will erect a new building in San Francisco, was announced recently. The total investment of the land and building is expected to exceed $300,000. The building will include more than 100,000 square feet of floor space, consolidating under one roof all Westinghouse and subsidiary company activities in San Francisco. . . . . The general contract for construction of a new headquarters building in Atlanta has been let by Westinghouse to the Rust Engineering Co., Birmingham. The 6-acre building site is about two miles from the center of Atlanta. In addition to a service plant, the headquarters building will include the district sales offices, and warehouse, display rooms and offices of the Westinghouse Electric Supply Co., and the company's lamp, x-ray and merchandising divisions. . . . . The Westinghouse radio division is extending its manufacturing space in Baltimore to three times its original size. During this month the plant will have 194,000 square feet available for production of radio transmitters and receivers for the nation's expanding defense forces. By that time the employee roll is expected to number 1500, 5 times the average for recent years. . . . . Plans for the construction of a new storage building, with space of 10,000 square feet, at the plastics plant of the General Electric Company in Pittsfield, Mass. have been completed. The building will be used for the storage of compound materials for the Pittsfield, Meriden, Conn., and Fort Wayne, Ind., plants and is part of the long-range plan for Pittsfield operations of General Electric's plastics division. . . . . With the movement of personnel and equipment now completed, Chicago district activities of the General Electric and affiliated companies, formerly scattered in nine separate locations, are now housed in G-E's new $1,500,000 building in Chicago. Occupying an entire city block, the structure is seven stories high, of modern design, and equipped with the latest in lighting and air conditioning. . . . . Ferranti Electric, Inc., New York City, has enlarged its plant and production facilities involved in the manufacture of transformers and instruments more than 100 per cent since the first of February.

Sales Appointments.—The Okonite Company has opened its sixteenth district office at 1212 Comer Bldg., Birmingham, Ala. The newly appointed manager of this office is Dewey A. White, formerly sales engineer in the company's Atlanta office. . . . . Ernest C. Low has been appointed general manager of sales of John A. Roebling's Sons Co. He has been identified with the Roebling organization for 32 years. . . . . Percy Jenkins, associated with the Wickwire Spencer Steel Co. for many years is now manager of the Boston branch of the Roebling Company. . . . . Allis-Chalmers Manufacturing Co. has appointed Ralph R. Newquist manager of the company's district office at Houston, Texas. . . . . The Solar Manufacturing Corp., Bayonne, N. J., capacitor manufacturers, has designated the Ambos-Jones Co., 1085 The Arcade, Cleveland, O., as industrial sales engineers for the state of Ohio. . . . . The Roller-Smith Co., Bethlehem, Pa., has appointed the John W. Clarke Co., 327 S. LaSalle St., Chicago, as representatives for the Chicago territory. . . . . S. Allen Jacobs, general sales manager of Inca Manufacturing division of Phelps Dodge Copper Products Corp., has been elected a vice-president of the company. He will continue to maintain his headquarters at Ft. Wayne.

Trade Literature

Portable Tools.—1941 Catalog, 60 pp. Describes 132 portable electric tools of many types. The Black & Decker Mfg. Co., Towson, Md.

Fuse Cutouts.—Bulletin GEA 3448, 20 pp. Describes enclosed, indicating, and drop-out fuse cutouts. General Electric Co., Schenectady, N. Y.

Transformers.—Bulletin 111, 16 pp. Describes and illustrates the manufacture of large size power transformers. R. E. Uptegraff Mfg. Co., Scottdale, Pa.

Motors.—Bulletin B-6107, 28 pp., "Motors for Driving Power House Auxiliaries". Describes all types of motors of 1 hp and larger, suitable for power plant application. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Lead Sheath Cable.—Bulletin GEA-3394, 20 pp. Describes and illustrates processes for producing uniform, oxide-free, lead sheath on insulated cable. General Electric Co., Schenectady, N. Y.

Air Switchgear.—Bulletin 4009, 6 pp. Describes air switchgear for 2,500–5,000-volt duty utilizing type HV circuit breakers for steel enclosed switchboards. I-T-E Circuit Breaker Co., 19th & Hamilton Sts., Philadelphia, Pa.

Photometers.—Catalog E-72, 20 pp. Describes photometers and illuminometers for lamp testing, lighting surveys, photometric research and educational use. Leeds & Northrup Co., 4962 Stenton Ave., Philadelphia, Pa.

Line Hardware.—Des. Data 30-350, 8 pp. Describes various types and shapes of transmission line fittings such as strain clamps, distribution clamps, suspension clamps, yoke assemblies, hooks, clevises, etc. suitable for use on all classes of service for copper, ASCR and composite conductors. Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Penna.

Metal Clad Switchgear.—Bulletin GEA-2499 A, 32 pp. Describes metal-clad switchgear for high voltage installations up to 15 kva. These units, complete with circuit breaker and other associated equipment, are shipped assembled, ready for installation. General Electric Co., Schenectady, N. Y.

Bus Supports.—Bulletin 31-C. Describes unit-type indoor bus supports. Tables give ampere capacities of standard bus shapes such as round and square copper tubing, copper and aluminum bars, channels and angles, also physical data for strength calculations. With the fittings listed in this bulletin, 50,000 bus support combinations can be assembled. Delta-Star Electric Co., 2400 Fulton St., Chicago, Ill.

Insulators.—Catalog 24, 160 pp. Lists all O-B materials for transmission lines, distribution lines and substations, including standard and radio-proof pintype insulators, strain insulators and fittings, insulated clevis assemblies, standard, high-impact and smog-proof suspension insulators, suspension and strain clamps, suspension insulator fittings, other line hardware, pincap and post-type station insulators, oil-filled and dry-type apparatus bushings, entrance bushings and tubes, porcelain condensers, and control gaps. A simpler procedure for specifying bushings is introduced in this volume, and tables of recommended strain and suspension clamps for all commonly used conductors are included.

(Continued on page 10)

Let ACME ENGINEERS Help You

Transformer designing requires specialized experience, especially so when mechanical or electrical specifications and performance characteristics must be held to close limits. The multiplied experience of Acme transformer engineers, and Acme's transformer manufacturing facilities can relieve you of your transformer problems. Acme transformers are selected by large users on a "better performance basis." An Acme transformer engineer will consult with you on your request. Write

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Acme Electric TRANSFORMERS

BY ANY MEASUREMENT

the new TYPE KA circuit breaker is the BEST for its field of duty

The Type KA is a worthy companion for the larger Type KB which has already earned a place of leadership in electrical protection. Completely new in design, the Type KA, like the KB, combines more desirable operating features than any other circuit breaker available for its range of service.

Conservatively rated interrupting capacity 15,000 RMS amperes.

250 volts d-c 600 volts a-c

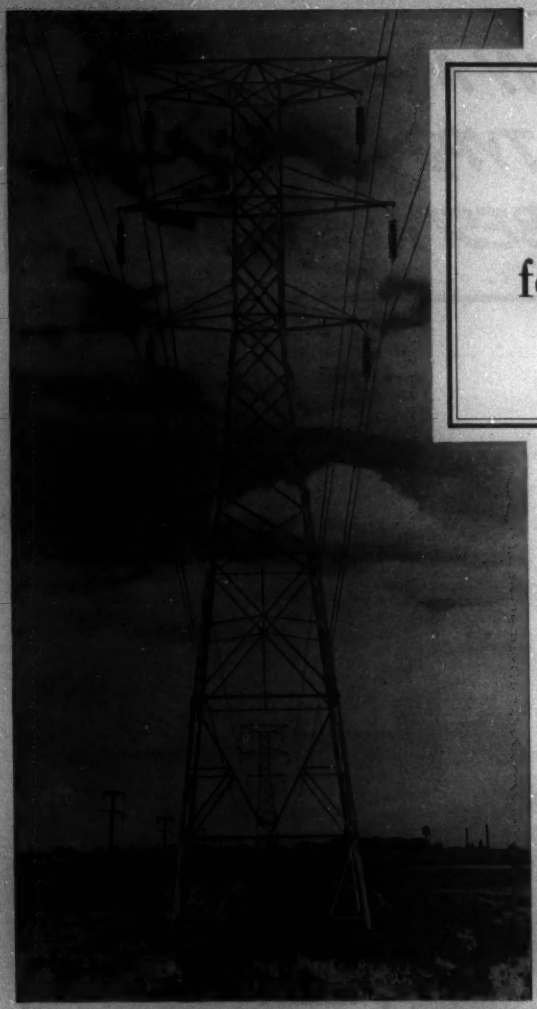
Measure the new Type KA Circuit Breaker for:

RESERVE INTERRUPTING ABILITY
COMPACTNESS
VERSATILITY in SERVICE
RUGGEDNESS
SPEED
SIMPLICITY

Send for Catalog 1501 which outlines and illustrates the essential features of Type KA

Representatives in Principal Cities

I-T-E CIRCUIT BREAKER CO., PHILADELPHIA, PA.



DESIGNED AND FABRICATED *by American Bridge Company, 310 towers carry the 132 K.V., double-circuit New Castle-Lenore Line in Indiana. Illustrated, one of the suspension type towers with standard American Bridge earth footings. Average height of towers is 94 feet.*

Towers of Strength for America's Power

Specialists in design and construction for every condition of climate and terrain

TOWERS of today have to carry high voltages for long distances . . . must provide adequate clearances for the power cables. Their design must give careful consideration to the character and accessibility of the terrain . . . to economical and durable construction . . . to simplicity and speed in erection.

Planning towers to meet any problem of service, terrain and weather — towers to do specific jobs and do them well—has been the aim of American Bridge engineers since 1905. In the intervening years, they not only have kept pace with the ever-growing needs of electric power transmission, but have developed many patented features which contribute to more effective and economical construction of America's power network.

A complete plant, ample in capacity and modernly equipped, is devoted entirely to the fabrication and galvanizing of all types of transmission towers. Its facilities include also the largest and most modern Test Frame in the country for testing even the tallest of line towers in present use. Whatever your tower requirements may be, the entire resources of American Bridge Company are at your service.

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UNITED STATES STEEL

WHY 5/8% STEPS MAKE YOUR REGULATION DOLLARS GO FARTHER!

BECAUSE THE DFR REQUIRES ONLY A fraction of the excitation current taken by older types of regulators, there'll be no need to install additional capacitors to balance the wattless current of these twelve DFR's ready for shipment to an eastern system.

Closer Regulation . . . Lower Excitation Current and Losses . . . Quieter Operation . . . Minimum Maintenance Add up to Impressive Savings. Here's How You Can Cut Your Regulation Costs with Allis-Chalmers 5/8% Step DFR Feeder Voltage Regulators!

CLOSER BAND width settings . . . lower excitation current . . . reduced losses . . . quieter operation . . . minimum maintenance costs — these are the five fundamentals of regulator economy. And they're the five reasons why utilities all over the country are installing Allis-Chalmers ⅝% Step DFR Regulators on their lines . . . why you'll want to get all the facts about this modern regulator that is revolutionizing regulation practice for single phase, 2400 to 6900 volt feeders.

First, and most important, a regulator must give accurate, sensitive regulation. That's where the DFR's small steps — only ⅝ of 1% — plus the flexibility of "Feather-Touch" Control, give you better operating results. Unhindered by the limitations of the conventional voltage control relay or the need of a motor brake to prevent over-shooting, the DFR permits band width settings within ±⅝%.

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You'll get complete information on the money-saving features of the Allis-Chalmers ⅝% Step DFR Regulator in our new bulletin B-6065. But the cost-cutting job these regulators can do for you is best told by themselves when you install them on your lines!

MEET REGULATION'S BIG FIVE!

1. CLOSER REGULATION!
2. *LOWER EXCITATION CURRENT!
3. REDUCED LOSSES!
4. QUIETER OPERATION!
5. MINIMUM MAINTENANCE COSTS!

*** LOOK AT THE BOX SCORE for the Savings Possible Because of DFR'S Lower Excitation Current!**

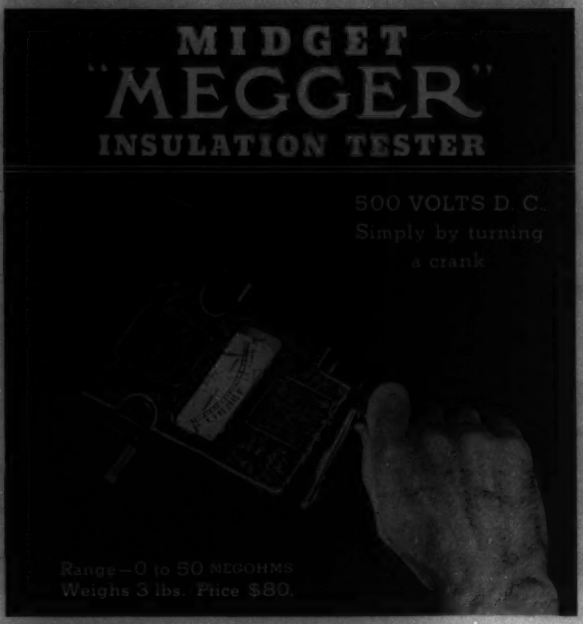
A	11	270	90	330	1,350
B	1200	30,000	10,000	20,000	150,000
C	1200	31,500	10,500	21,000	150,000

The Box Score shows three systems where large savings were possible with DFR Regulators. The figures in the second column from the right are the savings in excitation current possible with step regulators . . . while the right hand column represents the cost of fixed capacitors necessary to balance this excess wattless current. A 1515

These 5/8% Step Regulators Are Famous for Better Regulation at Lower Cost! Choose the Regulator to Fit Your Purpose!

DFR — 12 to 250 kva, single phase
AFR — 20.8 to 250 kva, three phase

ALLIS-CHALMERS



Protection Against Electrical Breakdowns

Here is a testing device that should be used today by every maintenance man who is seriously interested in forestalling electrical failures. Detects dirt, moisture and deterioration in the insulation of practically all types of electrical equipment. No batteries or any "adjustments." Independent of all external current. Simply turn the crank; read the scale. Can be carried in pocket or tool kit and is ready for use *any time* and *any where*.

"Meg" Insulation Tester
"Megger" instruments of this type here ranges up to 2000 megohms with hand generators up to 1000 volts.

Our Midget "Megger" Tester as well as other types of hand-driven and motor-driven "Megger" Insulation Testing Instruments is described in new Catalog 1685-EE just issued. Write for copy.

James G. Biddle Co.
1211-13 ARCH STREET *Electrical and Scientific Instruments* PHILADELPHIA, PA

Trade Literature

(Continued from p. 6)

Industrial Equipment.—Catalog 405, 96 pp. Describes flexible distribution systems for industrial plants; safety switches; lighting and circuit breaker panels and cabinets, and miscellaneous equipment. Bull Dog Electric Products Co., Detroit, Mich.

Motors.—Bulletin 0421-A, 4 pp. Describes totally enclosed, fan cooled, squirrel-cage induction motors. Bulletin 0411, 4 pp. Describes capacitor single-phase motors up to 20 hp. Century Electric Co., St. Louis, Mo.

Voltage Regulators.—Bulletin B-6126, 12 pp. Describes new, dry type, air-cooled regulators for feeder voltage regulation, in ratings of 36 kva to 96 kva, 2,400 volts, single phase. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Insulator Manufacture.—Bulletin B-2263. 16 pp. Describes and illustrates the process of porcelain insulator manufacture, from the raw material stage to the completed product. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Circuit Breakers.—Bulletin GEA-2165A, 8 pp. Describes type FK-142, 25,000-kva oil circuit breakers, 400 and 600 amperes, 7,500 volts; 800 amperes, 5,000 volts; 2, 3, and 4 poles and motor starting combination. General Electric Co., Schenectady, N. Y.

Tachometers.—Bulletin 750, 4 pp. Describes a new hand tachometer, direct reading, centrifugal type, available in four standard range combinations covering speeds between 30 and 48,000 r.p.m. Herman H. Sticht Co., Inc., 27 Park Place, New York City.

Circuit Breakers.—Catalog 3650, 8 pp. Describes class 250-OS-150 and 250-OS-230 oil circuit breakers for general distribution service. Catalog 3940, 4 pp. Describes type MS-2 subway oil circuit breakers for wall mounting in locations where total submersion is possible. Roller-Smith Co., Bethlehem, Pa.

Industrial Distribution Systems.—Bulletin 403, 44 pp. Describes an enclosed bus bar system of electrical distribution, providing flexible light and power circuits for industrial plants and commercial buildings, at minimum cost. Numerous installations are illustrated and much useful data in connection with applications are included. Bull Dog Electric Products Co., Detroit, Mich.

Connectors.—Catalog J, 80 pp. Describes a comprehensive line of electrical connectors; includes many new types developed for use in substations and underground systems. Specifications, prices and index are included. The unique numbering system simplifies specifying and ordering of any type of connector, whether listed in the catalog or not. Sheldon Service Corp., 24-15—43d Ave., Long Island City, N. Y.

Permits precision of application

● Precision in the application of "National" brushes to your equipment is made possible by the close degree of uniformity to which those characteristics affecting performance are held.

Careful analysis of raw materials, accurate compounding of mixes, close control of pressure, temperature and time in production processes, inspection at each stage of production, and determination of final characteristics and performance make "National" brushes outstanding in respect to uniformity.

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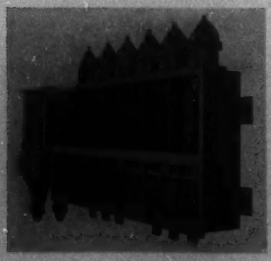
New Products

Breaker Operator.—A pneumatic operator for the high-speed operation of large outdoor oil circuit breakers, announced by Allis-Chalmers Mfg. Co., Milwaukee, Wis., and designated type PN-700, is especially

suitable for fast reclosing service, reclosing times within 20 cycles (60-cycle timing) having been obtained when used in conjunction with a standard 69-kv, 600-ampere, 500,000 - kva outdoor oil circuit breaker. The type PN-700 is also particularly suitable for installations where d-c supply is not available, and where operation from an a-c source through a rectifier is not considered desirable. The type PN-700 consists essentially of an air cylinder and piston, and a mechanically trip free mechanism. It uses a normal operating pressure range from 80 to 125 lbs. per square inch. An auxiliary compressed air storage tank stores enough air for three closing operations before recharging is necessary.

Vault Units.—Metal-clad units combining two or more devices, which are ordinarily installed separately, have been introduced by the G & W Electric Specialty Co., 7780 Dante Ave., Chicago, Ill. The type RAFCBH vault unit illustrated has a double throw selector oil switch (at the far end), six oil fuse cutouts on top, all attached



to a disconnecting link box having the conduit entrance compartment below. The busses in the boxes are fed from either one of the two incoming circuits. Two banks of transformers are connected through the disconnecting links in the box and in series through the oil fuse cutouts to the bus bars. The advantages of the combination units are primarily the safety features of metal-clad interconnections and the savings in labor of installation.

Improved High-Voltage Bushings.—Oil-filled apparatus bushings manufactured by the Ohio Brass Co., Mansfield, Ohio, have been improved by four distinct features—complete sealing, a magnetic oil level indicator, greater use of internal porcelain, and an interchangeable terminal system for transformer units. All of these changes were incorporated without altering the basic design principles of using porcelain as the main internal dielectric and using the full compression type of assembly in conjunction with butt-type joints. Complete, permanent sealing, offered on all class L and class G bushings, was accomplished by redesigning the oil expansion chamber to make it absolutely air and oil-tight. The units are filled to the proper level with the correct grade of insulating oil and sealed at the factory. Sampling of oil is unnecessary; the bushings may be stored or handled in any position at any time without loss of oil, and the units may be installed immediately upon delivery since the addition of oil and other servicing is not required. Magnetic oil level indicators are now furnished on the expansion chambers of all class G bushings (illustrated). This new type of gauge can be read easily from a considerable distance. It indicates the proper oil level over a wide range of temperatures, and it eliminates the possibility of gauge-glass oil leaks. More internal porcelain is being used in the new bushings than in previous designs. No other dielectric material than porcelain is used externally, and porcelain barriers in combination with oil form the internal insulation. With the new interchangeable terminal system, each transformer bushing is suitable for many terminal combinations, thus reducing the number of bushings to be kept in stock by users for various applications. The design employed allows either draw cable or fixed conductor terminal connections to be made or rearranged at any time without disturbing the bushing oil seal.

Varnished Glass Cloth.—Impregnated and coated with heat resisting varnishes developed especially for this purpose, glass cloth is now available for use as insulation by manufacturers of electric motors, generators and similar equipment. This new insulation material, known as Irvington Varnished Fiberglas, is furnished in full-width rolls and tape of various widths and thicknesses by the Irvington Varnish & Insulator Co., Irvington, N. J. The material consists of a woven glass cloth base (Owens-Corning Fiberglas) impregnated and coated with a special varnish which greatly increases its resistance to abrasion, impact, and increases its overall mechanical strength. The resulting material has higher insulation resistance and greater ability to withstand heat, enabling manufacture of

(Continued on page 16)

CLASSIFIED ADVERTISEMENTS

RATES: Fifty cents per line; minimum charge based on use of five lines; maximum space not to exceed thirty lines. Copy is due the 15th of the month preceding publication date.

WANTED: Sales Engineer for expanding, long established electrical manufacturer. Salary basis. Location, New York City. Outline experience. Address Box 211, ELECTRICAL ENGINEERING, 33 West 39th St., New York City.

ELECTRICAL ENGINEERS

Large manufacturer in northeast industrial area has employment opportunities for engineering graduates planning manufacture of product, developing machines and processes, reducing costs. Desire men of high scholastic record, few years manufacturing experience, aggressive but pleasing personality, creative ability of major importance. Must be citizens United States. State age, education, standing scholastically, experience in some detail, salary desired. Include photo. Address Box 210, ELECTRICAL ENGINEERING, 33 West 39th St., New York City.

Looking for a position in the technical field? The large technical agencies list their many employment opportunities in the New York Herald Tribune. For current openings check this newspaper daily and Sunday.

Reputable business executive desires connection as Southwestern Distributor. Able to furnish any bonds necessary. Box 1552, Dallas, Texas.

WANTED: Transformer Designing Engineer with experience in design of small distribution transformers. Location northern Ohio. State age, salary expected, and full details of experience in first letter. Position permanent. Address Box 204, ELECTRICAL ENGINEERING, 33 West 39th St., New York City.

MOTORS FOR SALE: Three 75-hp, 3-phase, 60-cycle, 2,300-volt vertical motors. Two G-E, one Westinghouse, all with starters. Write E. C. Whitener, Valley Station, Kentucky.

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THE I. T. & T. Selenium Rectifier is not a plane, a tank, a battleship or other instrument of war... but wherever direct current is required from an A. C. source, it is becoming more and more popular among the manufacturers of national defense equipment.

Low back leak, compactness, wide temperature range, mechanical and electrical stability are but a few of the outstanding features of these rugged but light weight rectifiers which have met successfully every rigid test given them by Government Defense Departments in their search for the best.

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INTERNATIONAL TELEPHONE DEVELOPMENT CO., INC.

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Complete Load-Frequency Control, Frequency and Time Error Recorder, Station Load Recorder and Tie-Line Load Recorder with System Error Printer, and Micromax Temperature Recorders for generator stators, generator fields and transformers are on this panel

Tie Line Load Schedules Held With Help Of L&N Controllers

That interconnected power systems require automatic control for maximum system efficiency is well appreciated. Elimination of the human equation and coordination of the regulating effort in various areas is possible with Leeds & Northrup Load-Frequency Control. Tie line load interchanges can be held to a prearranged schedule, and the full benefits of interconnection can be realized.

L&N control permits the same flexibility of operation as manual control and also embodies features beyond the scope of manual control. But most important of all its advantages is the fact that automatic control *continuously* supervises regulation in accordance with the requirements of a given area.

Modern Load Dispatching

System operators no longer rely entirely upon the telephone for load data. They now have reliable information about load conditions automatically charted before their eyes. Telemetered from any reasonable distance, the information is recorded so that a glance at the chart shows trends, peaks and other characteristics of the load.

Micromax is the instrument which is bringing this graphic picture to system operators all over the country. With it, they are raising system efficiency through better load scheduling.

Information about the solution of a specific problem will be sent on request. In writing us, please give as many details as possible regarding the nature of the load and the considerations which govern its distribution.

The Load Dispatcher for a large midwestern steel mill can tell in a moment just where his power is going and what the total is. Ten Micromax Load Recorders give him the data.

Naval Stores Power Plant Gets Constant Frequency With Micromax Control

Power requirements at the Brunswick, Ga., Plant of the Hercules Powder Co. recently called for an electrical supply of more uniform frequency. To meet these demands, power engineers installed one of the Micromax Industrial-Type Frequency Controllers.

Asked about the performance of this Controller, the Company now writes: "As the frequency of our power was not as constant as that held by the large public utilities today, Hercules installed . . . (a Micromax) . . . frequency controller to improve that factor. The controller does an excellent job and very satisfactorily remedies the prior condition."

Installed to improve frequency, this Micromax Industrial-Type Frequency Controller, "very satisfactorily remedies the prior condition," at Hercules Powder Company's Brunswick, Georgia, Naval Stores Plant.

One of the most interesting facts about this installation is that it was connected and started without any help except the standard instructions. Micromax Industrial-Type Frequency Controllers are as simple to operate and maintain as they are to install.

We'll be glad to send you a copy of Catalog N-56-161(1) which describes the equipment. Write for a copy.

Jrl Ad N-161(3)

LEEDS & NORTHRUP COMPANY, 4962 STENTON AVE., PHILA., PA.

LEEDS & NORTHRUP

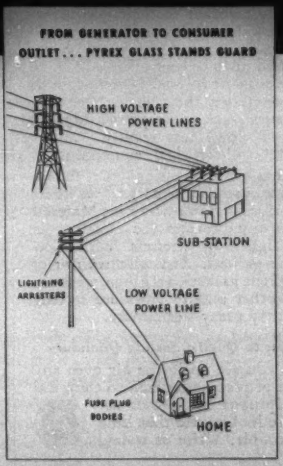
Three strikes, and your lights aren't out!

HERE'S an actual photograph of lightning hitting a power line. Maybe some of you remember the old days when this might easily have meant shattered insulators, smoking ruined transformers, hours of work for repair crews to restore service.

Today when lightning strikes, you know the Pyrex Insulators will stick to their jobs all along the line. But did you know Corning Glass Works also makes Pyrex brand glass housings for lightning arresters to protect costly distribution transformers and sub-station equipment? In fact, Corning Glass contributes to the electrical industry right now in ten important ways with:

Power Line Insulators
Telephone Insulators
Cyclotron Insulators
Radio Insulators
Ozone Cylinders
Lightning Arrester Bodies
Neon Insulators
Power Fuse Tubing
Automobile Fuse Tubing
Fuse Plug Bodies

If you have a problem you think glass might solve, we invite you to write today. Or send for a free copy of our new phamphlet "Glass as an Electrical Insulator". Address Insulation Division, Corning Glass Works, Corning, N. Y.



CORNING *means* Research in Glass

Pyrex Insulators BRAND

WE'RE LOOKING FOR TROUBLE!

IF you make (or use) electrical equipment, your success depends upon the reliability of the vital sealing units used therein. So, in part, does your company's expense budget. For gasket failures cause power failures and downtime losses; and, if you're a manufacturer, gasket failures mean loss of customers.

Whether you're concerned with switches, bushings, transforme's, cables, potheads, or circuit-breakers, our belief is that it will pay you to investigate Armstrong's Corprene. "Corprene" is the trade name for a group of more than two dozen cork-and-synthetic-rubber compositions—made in sheets, cut pieces, and molded forms. These materials are impervious to liquids and gases and highly resistant to their destructive effects; also to those of sunlight and corona. Corprene seals can be depended upon to keep oil in and moisture out—*for the life of your equipment.* Furthermore, their physical characteristics (such as compressibility and lateral flow) are readily "tailor-made" to individual requirements.

That's why Westinghouse, for instance, uses Corprene gaskets in its transformers; and why Line Material Company protects the isolators in its lightning arresters with Corprene gaskets. And why *millions* of Corprene gaskets, packings, washers, and other sealing units are serving industry today—efficiently.

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If you are up in the air over any kind of problem related to electrical equipment seals—*tell us.* We're looking for that kind of trouble. Write us today!

ARMSTRONG'S Corprene
COMPOSITIONS OF CORK AND RUBBER-LIKE MATERIALS

ARMSTRONG CORK COMPANY
INDUSTRIAL DIVISION
943 Arch Street Lancaster, Pennsylvania

New Products

(Continued from page 12)

lighter, smaller motors for any given horsepower rating and safer operation of these motors under continued overloads. In addition to the manufacture of standard thicknesses (.005 to .012 inches), widths (up to 36 inches) and colors (black or yellow), the company is prepared to cooperate with manufacturers in developing special combinations of various Fiberglas base cloths.

Carrier Current Capacitors.—Three new units, C-1003, a carrier current coupling capacitor, and C-1001 and C-1002 capacitors for carrier current traps, have been added to its line by the Cornell-Dubilier Electric

Corp., South Plainfield, N. J. The new type C-1003, a low voltage coupling capacitor, is available in two sizes, and in all capacities up to .075 mfd. and voltages up to 15,000 volts. These units, impregnated and filled with Dykanol "C", are designed with low stress to give long, dependable service. The two new capacitors for carrier current traps are designed to meet severe working conditions. One is of the fixed capacity type whereas the one illustrated is adjustable over a wide range of values. They are of the oil filled mica dielectric type, sealed in welded steel cases. High voltage wet process porcelain bushings are provided for terminals.

Bus Support Clamps.—To simplify the installation of flat bar bus structures, Burndy Engineering Co., Inc. 459 East 133d St., New York City, offers the type

HHV bus support clamp. This clamp supports the flat bar vertically and the same clamp may be used to hold one or more flat bars. If the supporting insulator is slightly out of line with other insulators a "slide track" in the clamp permits compensation so that the flat bar itself remains straight and true, without any stresses thereon tending to distort it. Both of the clamping plates which grip the flat bar are securely fastened to the base so that any short-circuit stresses are divided over both parts and are not concentrated on a single supporting part. These clamps are made of high strength aluminum bronze and are available for any number of bars of $1^1/_2$ inch to 12-inch width.

Safety Transformer.—A non-inflammable, synthetic liquid replaces oil in the "Noflamol" transformers developed by the Wagner Electric Corp., 6400 Plymouth Ave., St. Louis, Mo. As fireproof vaults are unnecessary where these transformers are employed, installations costs are reduced; also, they can be located in out-of-the-way places, or near the ceiling, releasing valuable floor space for other purposes.

Combination Cabinets.—In the new "2100" line of combination meter and current transformer cabinets introduced by the Meter Devices Co., Canton, Ohio, the meter panel with test block bridge is removable as a unit. Maximum working

space is afforded when installing transformers and wiring in cabinets. Meters and test switches may be wired in the laboratory. The cabinets are designed for use with low voltage current transformers, accommodating three units.

WANTED

Copies of the October and November (1940) issues of ELECTRICAL ENGINEERING. Please mail (parcel post) to American Institute of Electrical Engineers, 33 W. 39th St., New York City, printing your name and address upon the enclosing wrapper. Twenty-five cents, plus postage, will be paid for each copy returned.

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THIS completely self-contained bridge, with built-in 1,000-cycle and d-c power supplies, is direct reading in resistance, inductance, capacitance, dissipation factor (R/X), and storage factor (X/R or Q) over extremely wide ranges. Always set-up and ready to use, it is proving very valuable in hundreds of laboratories or factories. Its very wide ranges . . . its portability . . . its direct-reading feature and its simplicity of operation all contribute to the continued popularity of this instrument as one of General Radio's most widely used bridges.

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GENERAL RADIO COMPANY

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BRANCHES: NEW YORK AND LOS ANGELES

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Here at one source is the largest, most complete stock of close-control rheostats, wire-wound resistors and high-current tap switches in the world. Hundreds of thousands of units in a wide range of types and sizes—available for immediate shipment. Thousands of cores more on hand, ready to be processed into the exact units you require—available with many types of terminals and mountings. Ohmite Engineers also will be glad to assist you in designing special units. ★ *Write for your copy of the 96-page Ohmite Industrial Catalog and Engineering Manual No. 40.*

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CAPACITORS
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BAYONNE, N. J.

for Communications and Industrial Applications

DO THREADED INSULATORS GIVE YOU TROUBLE?

Threaded insulators CAN be made accurate and within close dimension tolerances, even when used as part of a metal assembly. If you've had "thread trouble" — send your problem to Universal. Universal *dry process* insulators speed production and insure performance. Send sample or dimension drawing for quotation.

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FLEXIBILITY	Excellent at all temperatures down to	-4° F.	32° F.
TENSILE STRENGTH	of No. 8 tubing, in lbs. per sq. in.	2000	2000
HEAT RESISTANCE	will not crack when bent over A.S.T.M. specification mandrel, after heating at 220° F. for	120 hrs.	more than 240 hrs.
FIRE RESISTANCE	A.S.T.M. specification	won't support combustion	won't support combustion
OIL RESISTANCE	heated in transformer oil at 230° F for 48 hours	slight stiffening	slight stiffening
DIELECTRIC STRENGTH	volts per mil up to .022" wet volts per mil up to .022" dry	350 750	400 750
SOLVENT RESISTANCE	both resistant to following	all petroleum solvents—benzol—toluol—denatured alcohol—acid (10% conc.)—alkalies (10% conc.)	

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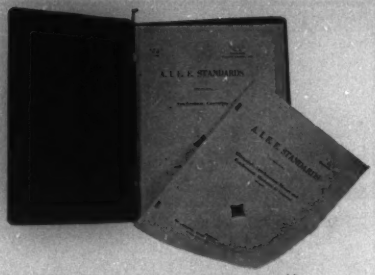

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24 Protector Tubes	40 Electrical Recording Instruments.
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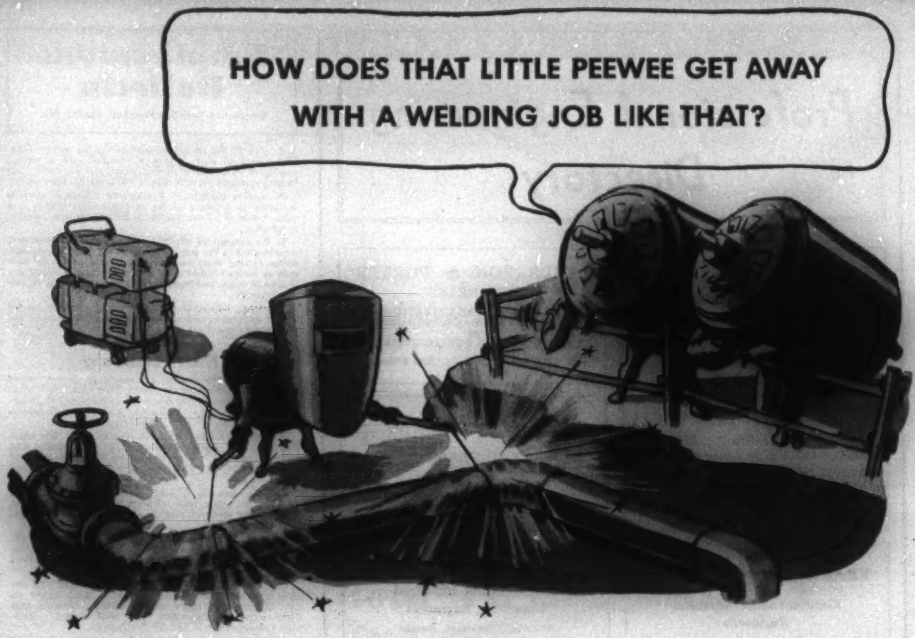

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It was small, inexpensive, and so designed that two men could weld from the same unit at the same time. This meant two leads and of course a correspondingly larger output of current from the generator. But here was the hitch.

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If you have tough jobs around your plant, you get a highly superior "tough job" electrical insulation in Fiberglas. For Fiberglas resists heat, chemical vapors, moisture, and most types of process dust *better than ordinary electrical insulations.*

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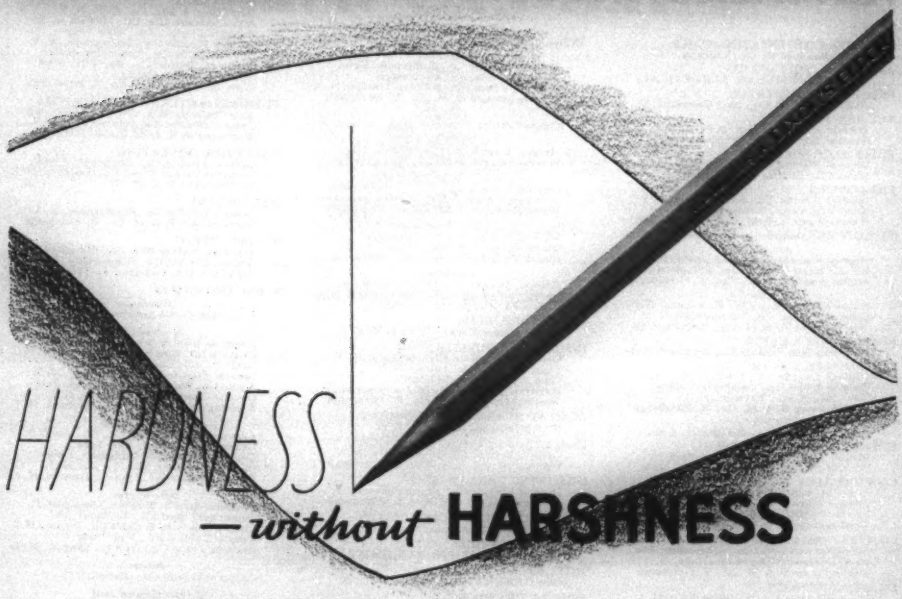

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Ohio Brass Co., Mansfield, O.

POLE MOUNTS
Malleable Iron Fittings Co., Branford, Conn.

PORCELAIN, ELECTRIC
Universal Clay Products Co., Inc., Sandusky, O.

RECTIFIERS
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
General Electric Co., Schenectady, N. Y.
International Tel. Dev. Co., Inc., New York
Westinghouse E. & M. Co., E. Pittsburgh

REGULATORS, VOLTAGE
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Sola Electric Co., Chicago, Ill.
Westinghouse E. & M. Co., E. Pittsburgh

RELAYS
General Electric Co., Schenectady, N. Y.
I-T-E Circuit Breaker Co., Philadelphia
Roller-Smith Co., Bethlehem, Pa.
Weston Elec. Instrument Corp., Newark, N.J.
Westinghouse E. & M. Co., E. Pittsburgh

RESISTORS
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
International Resistance Co., Philadelphia
Ohmite Mfg. Co., Chicago
Shallcross Mfg. Co., Collingdale, Pa.
Westinghouse E. & M. Co., E. Pittsburgh

RHEOSTATS, LABORATORY
General Electric Co., Schenectady, N. Y.
International Resistance Co., Philadelphia
Ohmite Mfg. Co., Chicago
Westinghouse E. & M. Co., E. Pittsburgh

STEEL, ELECTRICAL
Carnegie-Illinois Steel Corp., Pittsburgh

SWITCHBOARDS
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
General Electric Co., Schenectady, N. Y.
I-T-E Circuit Breaker Co., Philadelphia
Westinghouse E. & M. Co., E. Pittsburgh

SWITCHES, AUTOMATIC TIME
General Electric Co., Schenectady, N. Y.
Mineralac Electric Co., Chicago

SWITCHES, DISCONNECT
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

SWITCHES, GENERATOR FIELD
I-T-E Circuit Breaker Co., Philadelphia

TOWERS, TRANSMISSION
American Bridge Co., Pittsburgh

TRANSFORMERS
Acme Elec. & Mfg. Co., Cuba, N. Y.
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Kuhlman Electric Co., Bay City, Mich.
Sola Electric Co., Chicago
Westinghouse E. & M. Co., E. Pittsburgh

TURBINES and TURBINE GENERATORS
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

VARNISHES, INSULATING
General Electric Co., Bridgeport, Conn.
Irvington Varnish & Ins. Co., Irvington, N. J.
Westinghouse E. & M. Co., E. Pittsburgh

WELDERS, ARC
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

WELDING WIRE
American Steel & Wire Co., Cleveland, O.
General Electric Co., Schenectady, N. Y.
Roebling's Sons Co., John A., Trenton, N. J.

WIRES AND CABLES
Aluminum
Aluminum Co. of America, Pittsburgh
Armored Cable
American Steel & Wire Co., Cleveland, O.
Crescent Ins. Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Asbestos Covered
American Steel & Wire Co., Cleveland, O.
General Cable Corp., New York
General Electric Co., Bridgeport, Conn.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Bare Copper
American Steel & Wire Co., Cleveland, O.
Copperweld Steel Co., Glassport, Pa.
Crescent Ins. Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
Roebling's Sons Co., John A., Trenton, N. J.
Bronze
Copperweld Steel Co., Glassport, Pa.
Copper Covered Steel
American Steel & Wire Co., Cleveland, O.
Copperweld Steel Co., Glassport, Pa.
General Cable Corp., New York
Flexible Cord
American Steel & Wire Co., Cleveland, O.
Belden Mfg. Co., Chicago
Crescent Ins. Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Heavy Duty Cord
American Steel & Wire Co., Cleveland, O.
Crescent Ins. Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Lead Covered (Paper and Varn. Cambric Ins.)
American Steel & Wire Co., Cleveland, O.
Crescent Ins. Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Okonite-Callender Cable Co., Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Magnet
American Steel & Wire Co., Cleveland, O.
Belden Mfg. Co., Chicago
Crescent Ins. Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Roebling's Sons Co., John A., Trenton, N. J.
Rubber Insulated
American Steel & Wire Co., Cleveland, O.
Crescent Ins. Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Tree Wire
American Steel & Wire Co., Cleveland, O.
Crescent Ins. Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
Kerite Ins. Wire & Cable Co., New York,
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Weather proof
American Steel & Wire Co., Cleveland, O.
Crescent Ins. Wire & Cable Co., Trenton, N.J.
Copperweld Steel Co., Glassport, Pa.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

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"I WAS A LINEMAN"

"I WAS A DRAFTSMAN"

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About that time, the 18 men who are now the presidents of the Bell telephone companies were starting their careers. For, like the head of the System, they have worked many years in the business — an average of 38 years each. Each of them can say: "I was a clerk," "I was a lineman," "I was a draftsman"— and so on.

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Available in three types for different classifications of use, the IRC Coatings provide the utmost protection when it is required, or pave the way for dependable economy when it is not.

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